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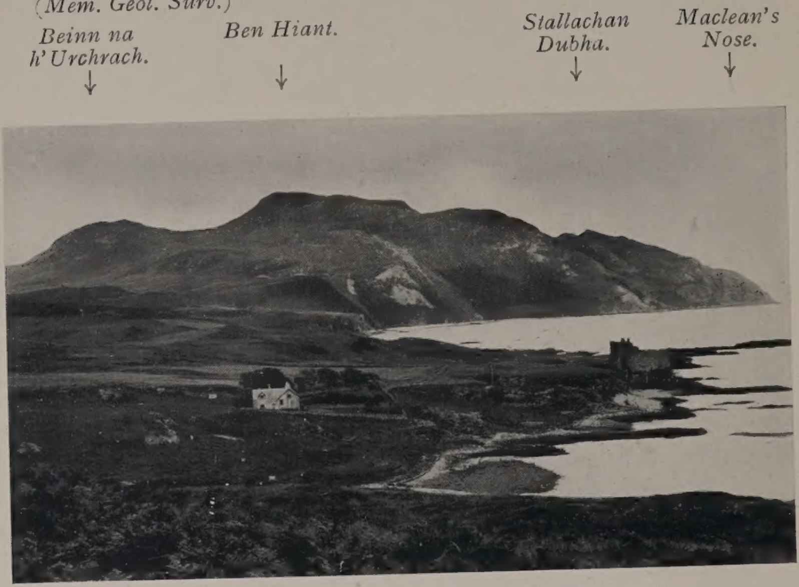
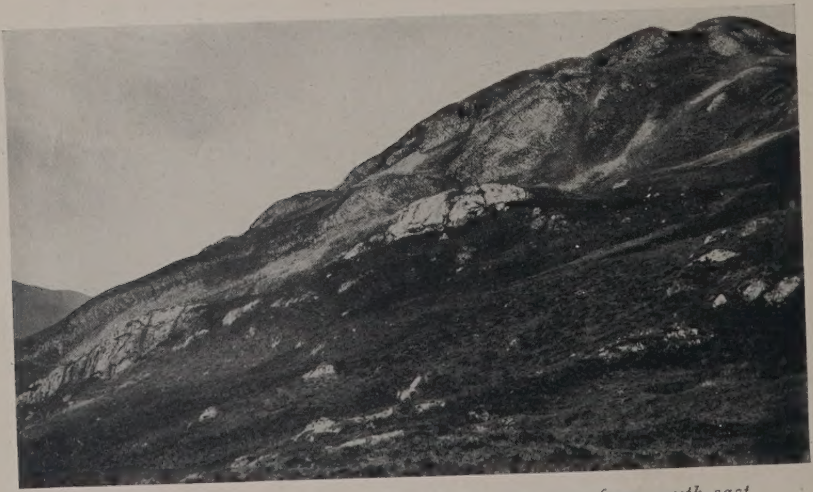
PLATE I.


Beinn na h' Urchrach.
Ben Hiant.
Stallachan Dubha.
Maclean's Nose.

A.—*View of Ben Hiant, Ardnamurchan, from west.*
(For Explanation, *see* p. viii.)



B.—*Marginal Scarp of Ben Hiant Intrusion, seen from south-east*
(For Explanation, *see* p viii.)

DEPARTMENT OF SCIENTIFIC AND INDUSTRIAL RESEARCH

Memoirs of the Geological Survey, Scotland

The Geology of Ardnamurchan, North-west Mull and Coll

(A Description of Sheet 51 and part of Sheet 52 of the Geological Map)

By

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WITH CHEMICAL ANALYSES BY

E. G. RADLEY, F.C.S.; and B. E. DIXON, M.Sc., A.I.C.

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PREFACE

THE area dealt with in this Memoir is represented by Sheet 51 of the Geological Map (one inch to one mile) and part of Sheet 52. It includes the Island of Coll, the North-west of Mull, and the western part of the peninsula of Ardnamurchan.

The Survey of Mull was completed by Mr. Bailey and his staff in 1920, and accounts of the Tertiary and pre-Tertiary rocks of the island were published in 1924 and 1925 respectively. In the autumn of 1920 Mr. Richey commenced work in Ardnamurchan and continued in subsequent years the mapping of the Tertiary igneous complex. For a short period he had the assistance of Mr. Bailey and Mr. Simpson. The detailed survey of the Tertiary and pre-Tertiary rocks of Ardnamurchan was completed in 1923. In 1921 Mr. Bailey, with Messrs. Eyles and Simpson, completed the mapping of Coll. In 1924 Mr. Richey and Dr. Thomas revisited Ardnamurchan to investigate further the relative ages of individual intrusions in the light of evidence furnished by the microscopic petrology. Concurrently with the surveying, chemical analyses were prepared by Mr. Radley and Mr. Dixon of the ancient rocks of Coll and of the Tertiary igneous rocks of Ardnamurchan. Mr. Manson was responsible for the collection of fossils from the Mesozoic rocks, for rock collection, more especially during several traverses across portions of the Ardnamurchan igneous complex, and for the taking of the geological photographs to illustrate the Ardnamurchan district.

In the present Memoir Mr. Bailey, with Mr. Simpson and Mr. Eyles, has written an account of the Island of Coll; details of the geology of North-west Mull have been drawn from the published memoirs on that island; and the account of Ardnamurchan, as also the Memoir-map, is mainly the work of Mr. Richey. Dr. Thomas, working in close co-operation with Mr. Richey, is responsible for the petrology of the Tertiary igneous rocks.

The account of the palæontology of the Mesozoic rocks of Ardnamurchan was written by Dr. Lee, who unfortunately has not lived to see the publication of his work. His manuscript has been edited by Mr. J. Pringle, his successor in the Palæontological Department in Edinburgh.

The area surveyed and described by each officer who had been engaged in the district is indicated by the initials placed at the end of the various paragraphs. Similarly, palæontographical matter carries the initials of the late Dr. Lee, and the petrology those of the Petrographer.

The Tertiary igneous complex of Ardnamurchan is more or less equally divided between Sheets 51 and 52 of the Geological Map. Sheet 51 is wholly surveyed, and has been published, but the surveying of Sheet 52 is not yet complete. In order, therefore, that the Tertiary complex should be presented as a unit, a special Memoir-map has been prepared on a scale of one and a half miles to an inch, and is inserted in a pocket at the end of the volume.

The district is of special value, as it illustrates in a comparatively simple manner many of the remarkable and important features of British Tertiary intrusive activity that attained its grandest expression in Skye and Mull. It is remarkable for the number and variety of its successive episodes, and illustrates more particularly the centralized intrusion of ring-dykes and cone-sheets, while the almost entire absence of glacial deposits has contributed largely to the excellence of rock-exposures.

J. S. FLETT,
Director.

Geological Survey Office,
28 Jermyn Street, London, S.W. 1,
15*th May* 1930.

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PLATE I, A. View of Ben Hiant, Ardnamurchan, from west. Main mass of this rocky hill is Ben Hiant Intrusion (*see* Fig. 19, p. 160). Maclean's Nose to right is agglomerate. Junction of these rocks extends from shore up well-marked hollow, seen on photograph above Mingary Castle (*see also* Pl. I, B). Stallachan Dubha is formed of outlying portion of Ben Hiant Intrusion. Scarp-features in middle distance are due to cone-sheets. Mingary Castle stands on a craignurite sill. Promontory beyond is Rudha a' Mhile (Fig. 25, p. 177).

Geological Survey Photograph, No. C. 2829.

PLATE I, B. Marginal Scarp of Ben Hiant Intrusion, seen from south-east. The view is taken from west of Stallachan Dubha (*see* Pl. I, A and Explanation). The Ben Hiant Intrusion is closely jointed. Vent-agglomerate forming foreground contains two large masses of big-felspar basalt (p. 126), one in centre of view, the other to the left.

Geological Survey Photograph, No. C. 2850.

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Geological Survey Photograph, No. C. 2859.

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Geological Survey Photograph, No. C. 2848.

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Geological Survey Photograph, No. C. 2826.

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Geological Survey Photograph, No. C. 2785.

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THE
GEOLOGY OF ARDNAMURCHAN, NORTH-WEST MULL, AND COLL

CHAPTER I

INTRODUCTION

THE area described in this Memoir consists of the island of Coll, the north-west portion of the island of Mull, and the western part of the peninsula of Ardnamurchan. The first two districts are covered by Sheet 51 of the one-inch Geological Map of Scotland. The third extends from Sheet 51 for 5 miles eastwards into Sheet 52, and includes the whole of the Tertiary igneous complex of Ardnamurchan. Sheet 51 is published in a colour-printed edition showing the solid and drift geology. Sheet 52 has not as yet been completely surveyed. In order, therefore, to illustrate the Ardnamurchan igneous district in its entirety, a coloured map has been specially prepared for this Memoir (Pl. VIII).

Coll, which is over 12 miles in length from north-east to south-west, is situated some 9 miles west of the mainland of Ardnamurchan and 6 miles west of Mull. To the south, it is separated by a narrow strait from the island of Tiree (Sheet 42). North-west Mull lies south of the nose of the Ardnamurchan peninsula, the two bounding the common entrance to the Sound of Mull and Loch Sunart. The Sound extends south-eastwards from the area under description between Mull and the mainland of Morven, while Loch Sunart runs eastwards between Morven and Ardnamurchan. The three districts with which we are concerned are reached by steamer plying up the Sound of Mull from Oban, and calling at Tobermory (North-east Mull), Kilchoan (Ardnamurchan), and Arinagour (Coll).

In their physical features the three districts are widely different. The island of Coll is low-lying, being for the most part less than 200 feet above sea-level. The highest ground is formed by Ben Hogh, an isolated hill rising to 339 feet. North-west Mull may be described as hilly, its highest point being the summit of Càrn Mòr at 1122 feet. The north-westerly lineation characteristic of much of its scenery is largely due to erosion along north-west lines of weakness, chiefly determined by Tertiary dykes. The western end of the peninsula of Ardnamurchan is mountainous, though few of its peaks attain more than 1000 feet in height. The highest hill, Ben Hiant, in Sheet 52, reaches 1729 feet.

In Coll, outcrops of rock are frequent around the coast and also inland, but considerable areas are covered by raised-beach deposits, blown sand, and peat. To the two former the island largely owes its characteristic pasture lands. In North-west Mull there is much rough pasture and peat, more particularly around the heads of sea-inlets, such as Loch a'Chumhainn at Dervaig. Rock is frequently exposed, in cliffs along the coast and as scarps on the hill-sides. The scarps give rise to terrace featuring, and mark the outcrops of the more solid portions of the Tertiary plateau lavas, of which the district is mainly formed. Western Ardnamurchan is typically a country of bare rock, many of its hills being nearly devoid of vegetation. The nose of the peninsula is fringed by almost continuous rugged sea-cliffs, composed of Tertiary gabbro, which are well-known features of this coast. Only to the north-west and north, at Sanna and Achateny, and to the south around the head of Kilchoan Bay, are there any extensive areas of low ground.

The rocks encountered within the area range in time from Archæan to Recent, but there are wide gaps in the sequence. Two major unconformities are well illustrated. The first separates Highland Schists from the Mesozoic (Trias); the second, the Jurassic from the Tertiary plateau basalts.

The low-lying island of Coll, like its neighbour Tiree, is composed of gneisses and schists which repeat in all essential details the characteristics of the Lewisian of the North-West Highlands. A feature of particular interest is the interbanding of igneous and sedimentary material.

In the mountainous tract that forms the Ardnamurchan peninsula the oldest rocks belong to the Moine Schists, an assemblage that, farther north, overrides the Lewisian Gneiss together with the succeeding Torridonian and Cambrian sediments along the Moine Thrust-plane. Resting on the Moines with marked unconformity are stratified rocks of Mesozoic age, which range from Trias to the Inferior Oolite, and probably also include beds of the Great Estuarine Series. The Ardnamurchan development of these strata is characteristic of the Hebridean province, and the fossils of the Jurassic portion of the sequence allow of close correlations with the equivalent rocks in other districts.

The Tertiary igneous rocks that in turn succeed the Mesozoics include outliers of the great plateau group of lavas, which covers large portions of the adjoining island of Mull and mainland of Morven. The lava eruptions were followed by the formation of central vents and by localized intrusions of plutonic and hypabyssal habit, which supply the chief interest of the Ardnamurchan district. This central intrusive complex is one of several that are distributed along the western sea-board of Scotland and extend to the north of Ireland. It clearly demonstrates in the number of its successive intrusive phases a long lapse of time, as is also shown by the adjoining central complexes of Mull and Skye. Though covering a smaller area than these, and evincing less complexity, it is of especial interest to the student of igneous geology on account of the clearness with which it exemplifies many of the phenomena characteristic of the British Tertiary province.

The vast amount of denudation that has taken place since the close of the Tertiary igneous period is shown in Ardnamurchan, as well as in related districts, by the de-roofing and erosion of the Tertiary plutonic rocks, which must have consolidated under a thick cover.

An interesting feature of somewhat late date, found in North-west Mull and Ardnamurchan, is a pre-Glacial raised-beach platform, extending up to 140 feet above present sea-level. More recent crustal oscillations are indicated by the late-Glacial and post-Glacial raised-beach deposits that fringe the coasts and, in the case of Coll, extend well inland. Evidence of the Glacial period itself is supplied by striæ and erratics.

The above brief outline of the geology of the area is supplemented by introductory accounts of the various rock groups, which are included with the detailed descriptions in subsequent chapters. Such accounts will be found chiefly at the beginning of each chapter and also, in the case of the Tertiary igneous rocks, in special chapters devoted to this purpose.

The arrangement of the chapters in this Memoir is based on the geological time sequence, so far as this is known. In the case of the Tertiary igneous rocks of Ardnamurchan, however, this plan is not strictly adhered to. For example, volcanic vents are treated in the same chapter, although they do not all belong to the same period of activity.

J.E.R.

CHAPTER II

LEWISIAN COMPLEX OF COLL

INTRODUCTION

COLL is made up of highly crystalline metamorphic rocks cut by much later minor intrusions that have escaped metamorphism. The metamorphic rocks have always been grouped by geologists as a southern continuation of a prevalently gneissose complex, which constitutes practically the whole of the Outer Hebrides and much of the North-West Highlands. To this complex the name Lewisian is now commonly given. The correlation of the Coll complex with the Lewisian is based partly upon the nature of the rocks and partly upon their geographical position, and is not likely to be questioned. The following features may be cited as characteristic of Coll and also of the type regions farther north :—

(1) The great bulk of the complex is thoroughly crystalline and metamorphic.

(2) A large proportion consists of metamorphosed calc-alkali igneous rocks, basic, intermediate, and acid. In Coll, all these compositions are well represented, with a predominance of hornblende-biotite-gneiss, a type of frequent occurrence elsewhere.

(3) Metamorphosed sediments can be locally distinguished. In Coll these include magnesian-marbles ; in Tiree, immediately to the west, there are not only magnesian-marbles, but also graphite-rich schists. These two types of sediment are found in association again in Harris in the Outer Hebrides, and at Loch Maree in the North-West Highlands.

(4) There are many examples of so-called flinty crush-rock in Coll, Tiree, the Outer Hebrides, and the neighbourhood of Loch Maree.

The Lewisian Complex in the North-West Highlands is often unconformably overlain by a group of sediments, named Torridonian. and this, again unconformably, by fossiliferous basal Cambrian, The Torridonian unconformity is particularly impressive and, as a detail, it may be added that it is of later date than the many zones and veins of flinty crush-rock which have been recognized in the Loch Maree district. On this account the analogous flinty crush-rocks of Coll are classed in the present chapter as part of the Lewisian Complex.

MAJOR INTERBANDING OF ORTHO- AND PARA-GNEISSES

The igneous and sedimentary rocks in the Lewisian of Coll are, in spite of their metamorphism, sufficiently distinct to allow of their being separately mapped. As a result it has been found that they are interbanded with one another on a large scale, and, moreover, that the bands are isoclinally interfolded. The following major bands or zones have been distinguished :—

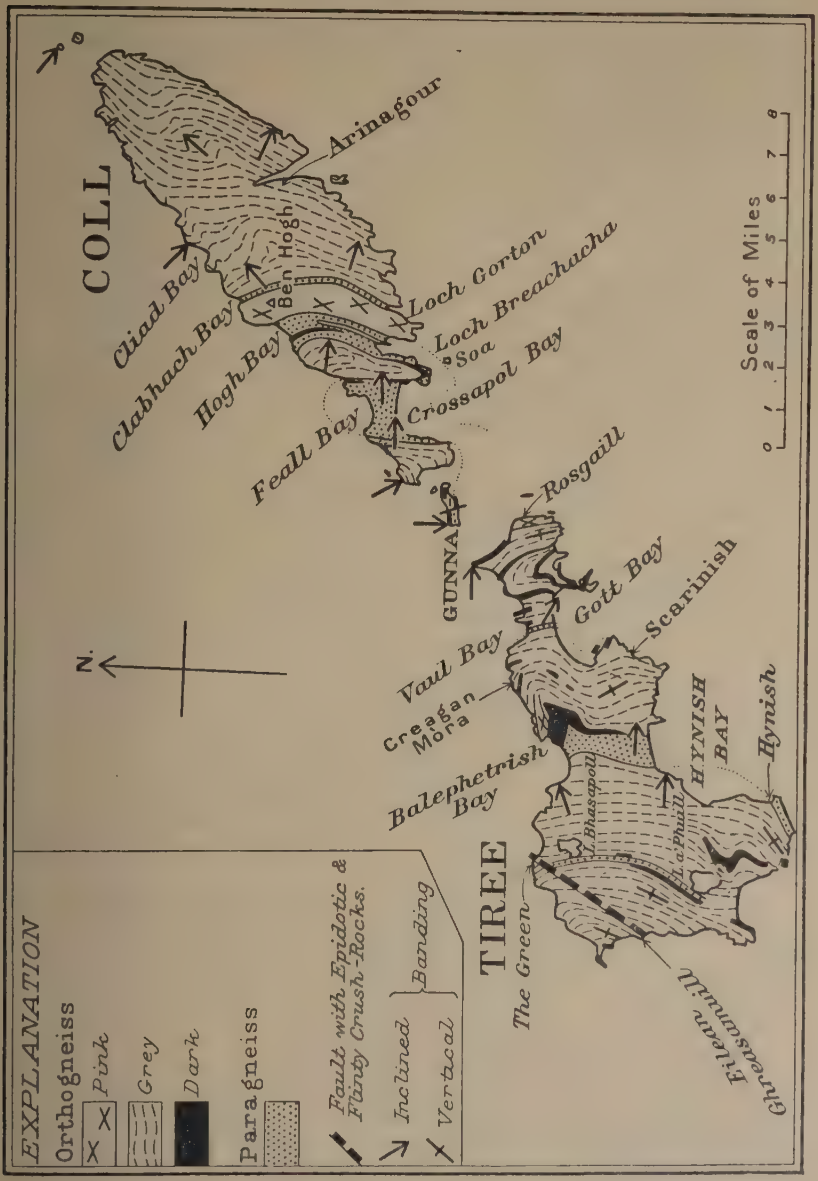
COLL
Arinagour
Ben Hogh
Cliad Bay
Clabhach Bay
Hogh Bay
Loch Gorton
Loch Breachacha
Soa
Crossapol Bay
Feall Bay
Scale of Miles
0 1 2 3 4 5 6 7 8
N.
Rosgaill
GUNNA
Gott Bay
Scarinish
Vaul Bay
Creagan Mora
Balephetrish Bay
HYNISH BAY
Hynish
L. Bhasapoll
L. a Phuill
TIREE
The Green
Eilean Ghreasamuill
EXPLANATION
Orthogneiss
Pink
Grey
Dark
Paragneiss
Fault with Epidotic & Flinty Crush-Rocks.
Inclined
Vertical
Banding

FIG. 1.—*Map of Coll and Tiree.*

(1) Western Zone of grey orthogneiss: in two detached outcrops west and east of Feall Bay.

(2) Feall Bay Zone of paragneiss: in two semi-detached outcrops at Feall Bay and Hogh Bay.

(3) Ben Hogh Zone of pinkish granite or granodiorite-orthogneiss.
(4) Gorton Zone of paragneiss.
(5) Eastern or Arinagour Zone of grey orthogneiss.

It is conceivable that this succession of zones may have resulted in part by duplication due to folding: that the Ben Hogh granite-gneiss (3) may be in the core of an isoclinal fold, and that the flanking Zones 2 and 1 may be fold-repetitions of 4 and 5. The lithological resemblances of the two flanking series of zones is sufficiently close to allow of this suggestion. For instance, it is practically certain that the paragneiss zones (2 and 4) belong to a single stratigraphical system. On the other hand, Zone 2 is very much thicker than Zone 4, and it therefore appears probable that Zones 2 and 4 are not fold-repetitions but that they have been separated from one another by the intrusion of the Ben Hogh granite-gneiss (3).

However we regard this particular case, it remains practically certain that Coll furnishes instances of two kinds of interbanding, the one due to intrusion and the other to subsequent interfolding. As an example of interbanding by intrusion let us consider the Feall Bay paragneiss (2). This paragneiss separates, in its Hogh Bay outcrop, two easily distinguished zones of orthogneiss, (1) the Western zone of predominantly grey banded hornblende-biotite-gneiss and (2) the pinkish Ben Hogh granite-gneiss; and at each junction there appear to be intrusive contacts. As an example of interbanding by isoclinal folding we may take that portion of the Western outcrop of the grey orthogneiss of Zone 1 which separates the paragneiss outcrops of Feall Bay and Hogh Bay from one another, though both belong to Zone 2. The inclination of the banding of the rocks is steep and isoclinal, roughly speaking, towards the east. Followed to the south coast the orthogneiss outcrop narrows down to nothing and allows the bordering paragneisses to come together. This may be ascribed to folding because a well-marked band of dark orthogneiss, which locally occurs at the junction of the grey orthogneiss and the paragneiss, continues in this position round the end of the grey orthogneiss outcrop.

Somewhat similar to the last-mentioned case, but not so pronounced in its development, is the fold-deflection of the Feall Bay outcrop of paragneiss westwards into Gunna. Here one sees clearly that the course taken by the outcrops is parallel with that of the banding, alike in the igneous and the sedimentary rocks.

A concealed fold-termination is indicated by a dotted line in Fig. 1, north of Feall Bay. This is inserted because, where folding takes paragneiss from Loch Breachacha by Caolas Soa and Eilean Tumala to Crossapol Bay, it leaves the Ben Hogh granite-gneiss out at sea somewhere west of Soa. Accordingly the two outcrops of grey orthogneiss that flank the paragneiss between Crossapol Bay and Feall Bay belong to folded repetitions of a single zone; and, unless there is a change of pitch, their outcrops will unite north of Feall Bay.

Two bands of igneous material, intercalated among the paragneiss that outcrops between Hogh Bay and Loch Breachacha, are almost as broad as the Gorton zone of paragneiss which has been included in our enumeration of the major zones of the Coll succession. One of these intercalations consists of dark orthogneiss traceable for a mile southwards from Hogh Bay, and the other of grey orthogneiss which has been followed for two miles northwards from Loch Breachacha. The outcrop of the dark gneiss is nearly 200 yards broad, and that of the grey gneiss is about 100 yards. In both cases exposures are too discontinuous to decide if the bands continue along their strike right across the island. Other examples of interbanding of igneous and sedimentary material will be noted in the sequel. Still, the zones classed as igneous include only an exceedingly small proportion of recognizable sedimentary material and *vice versa*.

It may be added that there is nothing at the junction of the sedimentary and igneous rocks of the Coll Lewisian to correspond with what is commonly called contact alteration. The metamorphic sediments are either gneisses or schists, not hornfelses.

There is another aspect of the structure of Coll to which a few words may be devoted. The succession of zones from the Western grey orthogneiss (1) to the Eastern or Arinagour grey orthogneiss (5) is structurally an ascending sequence, although this relation may have only a very limited and local significance. The Western orthogneiss Zone 1 protrudes as two outcrops southwards into the outcrop of the Feall Bay paragneiss (2). The more westerly of these protrusions extends westwards from Crossapol Bay into Gunna. It is of anticlinal form as shown by the dip of the orthogneiss banding, so that Zone 1 structurally underlies Zone 2 in this particular locality. Unfortunately, in the eastern outcrop of Zone 1 between Crossapol Bay and Hogh Bay, the banding-dips are so constantly in one direction as to furnish no information regarding the order of superposition. From the Hogh Bay outcrop of Zone 2, north-eastwards to the end of Coll, banding-dips are directed to some point of the compass between north-east and south-east, and accordingly Zones 2, 3, 4, and 5 follow one another in ascending sequence in this direction. Additional weight attaches to this observation because the banding-dips in the Eastern or Arinagour grey orthogneiss zone (5) are often at quite moderate angles, even under 20°. Moreover, the banding south of Cliad Bay is thrown into a well-defined syncline pitching north-eastwards.

PETROLOGY

ORTHOGNEISSES

Pinkish Granite-gneiss.—The Ben Hogh granite-gneiss, Zone 3, furnishes the only important example of its kind in Coll. Other minor occurrences will be mentioned at the end of this account.

The analysed specimen (Anal. I, 23020) is fresh and is a good representative of much of the Ben Hogh zone, though a little more basic than the average. In the hand-specimen this can be seen to

TABLE I

ANALYSES

	I.	A.	II.	III.	B.	IV.	C.	V.	D.	E.	VI.	
	Igneous.			Sed.	Ign.	Sed.	Ign.	Sedimentary.			Sed.	
Metamorphic or Non-metamorphic.	Met.	Non-met.	Met.	Met.	Non-met.	Met.	Non-met.	Met.	Non-met.		Met.	Metamorphic or Non-metamorphic.
SiO_2	68·97	67·00	66·19	81·89	79·19	76·15	63·03	64·23	67·92	59·96	18·29	SiO_2
Al_2O_3	14·66	15·19	15·58	9·10	9·88	5·55	17·72	15·87	12·89	16·52	2·77	Al_2O_3
Fe_2O_3	1·36	1·98	1·38	0·17	0·21	0·87	2·27	0·03	3·73	2·37	1·11	Fe_2O_3
FeO	1·92	2·17	2·90	0·16	0·63	0·82	1·92	3·84	2·42	3·20	nt. fd.	FeO
MgO	1·88	1·76	2·11	0·02	0·55	6·48	3·63	3·32	2·69	2·47	15·52	MgO
CaO	4·28	3·55	4·20	0·64	0·00	6·78	5·97	5·06	3·84	5·32	31·44	CaO
Na_2O	4·18	3·88	3·64	0·11	0·66	0·49	3·92	2·86	1·82	5·00	0·05	Na_2O
K_2O	1·42	2·99	2·18	7·11	7·68	0·66	1·06	1·68	1·59	2·82	0·78	K_2O
$H_2O+105°$ C. . .	0·47	0·77	0·63	0·21	0·54	0·46	0·44	0·84	0·89	1·27	4·01	$H_2O+105°$ C.
$H_2O-105°$ C. . .	0·03	—	0·04	0·03	0·03	0·08		0·05	0·17	0·15	0·51	$H_2O-105°$ C.
TiO_2	0·38	0·51	0·54	0·06	0·00	0·12	—	0·67	0·82	0·59	0·09	TiO_2
P_2O_5	0·13	0·13	0·13	0·07	0·00	0·45	—	0·13	0·06	0·24	0·22	P_2O_5
MnO	0·38	0·07	0·37	0·26	0·00	0·30	—	0·42	0·10	0·09	0·42	MnO
CO_2	0·13	—	0·39	0·28	0·64	0·95	—	0·10	1·28	trace	24·84	CO_2
FeS_2	nt. fd.	—	nt. fd.	nt. fd.	—	nt. fd.	—	0·88	—	—	nt. fd.	FeS_2
S	—	—	—	—	—	—	—	—	0·05	0·00	—	S
Cr_2O_3	—	—	—	—	—	—	—	trace	0·00	—	—	Cr_2O_3
(Co, Ni)O	nt. fd.	—	nt. fd.	nt. fd.	—	0·03	—	nt. fd.	—	—	nt. fd.	(Co, Ni)O
BaO	nt. fd.	—	nt. fd.	0·03	—	nt. fd.	—	0·04	—	—	nt. fd.	BaO
Li_2O	nt. fd.	—	nt. fd.	trace	—	trace	—	trace	—	—	trace	Li_2O
Cl	—	—	—	—	—	0·03	—	—	—	—	—	Cl
	100·19	100·00	100·28	100·14	100·01	100·22	99·96	100·02	100·27	100·00	100·05	

nt. fd.=not found.

I. (23020; Lab. No. 813.) Acid hornblende-biotite-gneiss (acid granodiorite-gneiss), representative of the 'granite-gneiss' of Ben Hogh (Lewisian). Shore cliffs, 375 yds. W. 11° N. of Ballyhaugh farm, Coll. *Anal.* E. G. Radley.

A. Mean of 17 analyses of various types of quartz-diorites of which 5 have been called granodiorite in original descriptions. From A. Osann (H. Rosenbusch), *Elemente der Gesteinslehre*, 1923, p. 188.

II. (23019; Lab. No. 811.) Hornblende-biotite-gneiss (granodiorite-gneiss), representative of the more acid of the 'grey orthogneisses' of Coll (Lewisian). Shore cliffs, 1155 yds. N. 25° E. of Clabhach Church, Coll. *Anal.* E. G. Radley.

III. (23026; Lab. No. 815.) Quartz-orthoclase (microcline)-granulite with a little muscovite (metamorphosed arkose) from Ben Feall outcrop (Lewisian). Shore cliffs, 358 yds. N. 10° E. of Trigonometrical Station, Ben Feall, Coll. *Anal.* E. G. Radley.

B. Felsite porphyry, Bahia Rodriguez, Patagonia. *Anal.* M. Dittrich. Quoted from P. Quensel, *Bull. Geol. Inst. Upsala*, vol. xii., 1914, p. 28.

IV. (23025; Lab. No. 812.) Quartz-(pale)amphibole-scapolite-rock with accessory apatite (metamorphosed dolomitic sandstone) from Clabhach outcrop (Lewisian). W. side of small bay, 280 yds. N. 33° W. of Clabhach Church, Coll. *Anal.* E. G. Radley.

C. Hypersthene-andesite, Mount Shasta, California. *Anal.* W. H. Melville. Quoted from J. S. Diller, *U.S. Geol. Surv. Bull.*, 150, 1898, p. 228.

V. (23027; Lab. No. 814.) Biotite-hornblende-andesine-quartz-granulite with an unusual proportion of hornblende (metamorphosed impure sandstone) from Hogh Bay outcrop (Lewisian). Shore cliffs, 1100 yds. N. 33° W. of Totronald, Coll. *Anal.* E. G. Radley.

D. Green sandstone of Old Red Sandstone (Devonian). Polletind, Norway. *Anal.* A. Vindenes. Quoted from C. F. Kolderup, *Bergens Museums Aarbok*, 1924–5 (1925), p. 33.

E. Green sandstone of Old Red Sandstone (Devonian). Bleien, Norway. *Anal.* A. Vindenes. Quoted from C. F. Kolderup, *Bergens Museums Aarbok*, 1924–5 (1925), p. 33.

VI. (23028; Lab. No. 816.) Forsterite (serpentinized)-phlogopite-marble (metamorphosed impure dolomitic limestone) from Clabhach–Gorton outcrop (Lewisian). N.E. of garden, inside roadside fence, 333 yds. S. 37° W. of Uig, Coll. *Anal.* E. G. Radley.

consist mainly of colourless quartz and felspar, streaked with dark biotite and hornblende; while a very occasional pink orthoclase appears like a relatively undeformed phenocryst. The microscope shows that the main minerals are oligoclase and quartz, aggregated for the most part in allotriomorphic crystals measuring about 1 mm. across; subordinate minerals are orthoclase, biotite, and hornblende; accessories are iron-ore, including pyrites, and apatite. The biotite is pleochroic from light to dark brown, and the hornblende from green to brownish-green. The orthoclase occurs as irregularly bounded patches and has partly passed over to microcline.

The structure of the gneiss is such as could easily be developed by squeezing a well-crystallized granite under conditions that allowed of plastic flow. The ferromagnesian minerals are streaked out into laminæ, but these are very impersistent and do not give rise to bands.

Analysis I agrees closely with Analysis A given by Osann as the mean of 17 analyses of quartz-diorite types, including 5 that were classed as granodiorites in the original descriptions. General usage seems to favour a silica percentage of about 69 as separating granodiorites from granites.[1] According to this criterion the analysed specimen is a granodiorite, and this agrees well with its content of 4·28 per cent of CaO and only 1·42 per cent of K_2O.

Other slices from the Ben Hogh Zone (21303, 21305, 21308, 23285) differ from the analysed material in showing no hornblende ; while the corresponding hand-specimens are in some cases definitely pink, rather than grey with pink crystals. In (21303) there is a somewhat pronounced though subangular idiomorphism of the oligoclase ; and in (21305, 21308) the potash-felspar occurs in perthitic intergrowth with oligoclase.

Away from the Ben Hogh Zone, pink granite-gneiss occurs only in a subordinate and often ill-defined fashion, which does not allow it to be shown on the published one-inch Map. A good example of potash-rich granite-gneiss runs as a narrow strip along the coast for half a mile north-east of Eilean nam Muc, east of Arinagour (22140). Though foliated it is associated at one place with an unfoliated syenite-like rock rich in stumpy green hornblende, microcline, and quartz, with secondary epidote and albite—probably something in the nature of a pegmatite (22142).

The pink or pinkish orthogneisses here described owe their colour to the presence of a fair proportion of potash-felspar. They must not be confounded with altered varieties of the normally grey orthogneisses, in which albitized plagioclase felspar often assumes a pink colour. The distinction between the more acid and the more basic gneisses in such cases is generally apparent, even in the field, because of different concentrations of ferromagnesian constituents.

Grey Orthogneiss.—Most of the rocks of Coll are classed as grey hornblende-biotite-orthogneiss, of more basic composition than the Ben Hogh granite-gneiss. Extensive slicing of material from comparable grey orthogneiss in Tiree has revealed the frequent occurrence of pyroxenic varieties, so it is probable that such rocks may also occur in Coll.

A feature of the grey orthogneisses is the prevalence of banding. This makes it difficult to secure a representative analysis. The material analysed (Anal. II, 23019) is a good fresh sample of one of the more acid varieties. It shows a well-marked banding with quartzo-felspathic layers, one or two centimetres thick, alternating with others which, while containing quartz and felspar, are dark with biotite and hornblende. The biotite occurs in flakes up to 2 mm. broad and is orientated approximately parallel to the banding. Under the microscope the quartzo-felspathic grains generally measure between 1 and 3 mm. across. Quartz, oligoclase, and orthoclase, passing to microcline, are all well represented with general allotriomorphic outlines. Strongly pleochroic brown biotite flakes bulk more largely than brownish-green hornblende in stumpy crystals. Pyrites and apatite are accessory. The analysis (II) is very close to that of the Ben Hogh granite-gneiss (I), but with lower silica. Some of the extra potash goes, with increased iron and alumina, into biotite.

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[1] V. A. Eyles and J. B. Simpson, 'Silica Percentages of Igneous Rocks,' *Geol. Mag.*, 1921, p. 438 ; *see also* E. B. Bailey *in* 'The Geology of Ben Nevis and Glen Coe,' *Mem. Geol. Surv.*, 1916, pp. 153, 159.

As compared with other slices of grey orthogneiss from Coll, the analysed material is unusually rich in potash-felspar, for often this mineral is practically absent. The biotite of the analysed rock is more abundant than the hornblende. This feature is quite common, for it reappears in many slices (21293, 21365, 21391–3, 21403, 21404, 23286, 23288–9, 23470, 23472–3). Slices with hornblende more abundant than biotite are (21294, 21352, 21402, 21420–1, 23467). One mineral sometimes occurs to the exclusion of the other, but, as a rule, an association of biotite with hornblende is characteristic of the grey orthogneisses. Myrmekitic intergrowth of oligoclase and quartz was noted in one slice only (21294).

In addition to a parallel structure, such as may be ascribed to plastic flow of a crystallized dioritic rock (21421), there is a very prevalent banding of lighter and darker constituents. Without attempting a full discussion of this banding, it may be pointed out that it is much more prevalent than is flow-banding in ordinary non-metamorphic igneous rocks, and that it can in special cases be traced to the deformation and partial assimilation of xenoliths.

Hornblendic layers in the grey orthogneiss, even where only a foot or two in thickness, may be traced continuously for several yards. These dark layers may be simple or complex, for some consist entirely of slightly banded hornblendic material, while others are freely veined by coarse hornblendic pegmatite. Where veining is the rule it frequently produces intrusion-breccias with hornblendic blocks enveloped in pegmatite, and these blocks as shown by their internal banding have sometimes been markedly deorientated.

Before leaving the subject of the grey orthogneisses, mention may be made of certain deceptive appearances due to alteration. In (21369) hornblende is replaced by calcite and chlorite, so that the rock weathers cariously like a ribbed impure limestone. In (23472) albitization has given rise to a pink colouration.

Dark Orthogneiss.—The rocks here classed as dark orthogneiss are of types commonly spoken of as amphibolite and pyroxene-granulite. They are typically composed of about equal proportions of felspar (oligoclase or andesine) and ferromagnesian minerals. The commonest among the latter is brownish-green hornblende (21368, 21401, 22141), sometimes in association with augite (23287). In two slices the predominant ferromagnesian mineral is augite, accompanied by abundant iron-ore (21374, 23469). Common accessory minerals are quartz and apatite. Garnet has been noted in various occurrences in the field. It has a sporadic tendency, and is present only in one slice (21368). The hornblende is stumpy and generally under 3 mm. long. The other minerals are rather shorter.

In many quite considerable outcrops these gneisses are very little banded. An augitic rock in the hand-specimen may closely resemble a fine gabbro (21374), but hornblendic varieties usually glisten very definitely when broken along their foliation planes.

Sir Jethro Teall[1] and other workers have shown that the types here considered result from metamorphosis of basic igneous rocks. This conclusion may be the more readily accepted because a gabbroic composition is indicated (1) by the mineral proportions of the augitic varieties, and (2) by chemical analysis in the case of a typical hornblendic variety selected from Tiree. Comparison of Coll and Tiree slices shows that the augite and iron-ore of the one type must be represented by the hornblende of the other. The hornblende has probably also received material from felspars, rejecting at the same time a certain amount of silica as quartz. Olivine is absent, as is always the case in metamorphic basic igneous rocks that retain felspar. Apparently olivine and felspar under conditions of regional metamorphism tend to react, and to yield either hornblende or garnet.

The material sliced may be grouped according to its field relations as follows :—

(1) Major bands shown on one-inch Map : Gunna (21401) ; east of Ben Feall (21374, 23469) ; west of Loch Breachacha (21368) ; Hogh Bay (23287).

(2) Minor bands not separately shown on one-inch Map : (22141, 22153, 23018).

The last-mentioned slice (23018) comes from a thin band in grey orthogneiss. It is a hornblende-felspar rock quite unusually rich in a hornblende that is of a pale blue-green instead of the usual brownish-green colour.

Felspar-free Rocks.—Felspar-free rocks, associated with the Coll orthogneisses, are only represented by two slices. The first (21394) is from a lenticle enclosed in a grey orthogneiss tongue invading paragneiss on the west shore of Crossapol Bay. It consists of pale blue-green hornblende and subordinate hypersthene, the latter furnishing a framework of very complicated character. The second slice (22152) is from a 3-ft. band in grey orthogneiss on the east shore of Loch Eatharna, near the entrance of the loch. Its main constituent is strongly pleochroic brownish-green hornblende, but there is also abundant biotite with pleochroism from yellowish to almost black. The Crossapol lenticle has probably resulted from the alteration of an olivine-rich basalt. The considerable potash of the Loch Eatharna rock suggests a possible derivation from lamprophyric material or from dolomitic shale.

Calcified Orthogneisses.—Three peculiar specimens taken from areas of somewhat calcareous sediment may represent products of interaction between this latter and grey orthogneiss. One (21318) comes from a little west of the Hogh Bay dark orthogneiss, the others (21395, 21396) from a couple of bands at the west end of Gunna. They differ from the normal metamorphosed calcareous sediments of Coll in having aegirine-augite as their main ferromagnesian constituent, and sphene as a conspicuous accessory.

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[1] J. J. H. Teall, 'The Metamorphosis of Dolerite into Hornblende-schist,' *Quart. Journ. Geol. Soc.*, vol. xli., 1885, p. 133 ; *also* 'Dynamic Metamorphism,' *Proc. Geol. Assoc.*, vol. xxix., 1918, p. 1.

In Tiree this combination is very characteristic of certain reaction products between dark orthogneiss and the Pink Marble, and can be shown to be dependent upon the association of iron and titanium, so characteristic of igneous rocks. Quartz and potash-felspar are present in all three slices, calcic scapolite in (21318, 21396), oligoclase in (21395, 21396), and calcite or carbonate in (21318, 21395). In several cases the carbonate is rimmed by 'cauliflower' growths of green augite or pale-green diopside which spread out into adjoining felspars and scapolite (p. 24).

A specimen (21398) from the dark orthogneiss outcrop mapped with associated marble (21399) on the south shore of Gunna consists of green diopsidic augite and calcic scapolite, along with abundant accessory sphene. The colour of the augite is intermediate between that of the aegirine-augite of the last specimens and the diopside commonly met with in the calcareous sediments. The rock exactly reproduces the characters of some of the reaction products between dark orthogneiss and the Pink Marble of Tiree.

Pegmatites.—There are many irregular highly felspathic intrusions in Coll to which the name pegmatite may be applied, although graphic structure is absent or very subordinate. These pegmatites show little or no foliation and generally measure only a few feet or yards across. They may be quite unorientated, or they may run in lenticular fashion along the banding of their host. The nature of these pegmatites varies fairly consistently according to the nature of their associates. In the grey orthogneiss the main minerals are oligoclase, potash-felspar, and quartz, with subordinate biotite. The crystallization is coarse and the colour may be white or pink. In the pegmatites of the dark orthogneisses large idiomorphic crystals of dark hornblende are frequently met with, and sometimes garnet is present. With the micaceous paragneisses west of Hogh Bay a distinctive compact white pegmatite is common. Among the paragneisses on the west shore of Loch Breachacha there are cross-cutting bands of quartzo-felspathic rock, which carry subordinate biotite and garnet, and exactly resemble some of the apparently bedded quartzo-felspathic material of neighbouring exposures. Similarly, white garnetiferous pegmatites are a feature of the paragneiss outcrops west of Feall Bay and at the west end of Gunna. It therefore seems certain that the various country rocks have contributed a considerable proportion of the substance of the pegmatitic intrusions.

SUPPOSED QUARTZ VEIN OF CLABHACH GORTON PARAGNEISS ZONE

On the shore of Clabhach Bay, and at intervals across the island along the course of the Gorton sedimentary zone, there are exposures of an extremely pure translucent quartz-rock that has a somewhat frosted appearance on fracture. Quite possibly the outcrop of this rock is continuous under the cover of superficial deposits. At Clabhach the band is only 15 ft. broad, but at the roadside at Acha it measures 200 ft. Under the microscope there is seen a minute stress granulitization of what must at one time have been very large individual crystals (21296, 26296). There are numerous little needles, possibly rutile; and in hand-specimens pink felspar crystals are occasionally seen. The rock is shown on the one-inch Map as a quartz vein, but it is possibly a metamorphosed sandstone of exceptional purity. If the latter alternative were proved it would add greatly to the interest of the Gorton sedimentary zone, for it would show that its course is parallel to original bedding.

PARAGNEISSES

The metamorphosed sediments of Coll show a variety of types, including highly quartzose granulites, magnesian marbles, biotite-granulites, and many interesting intermediate varieties. Thoroughly aluminous material is unrepresented, as is shown by the extreme rarity of muscovite, the very moderate development of garnet, and the apparent absence of sillimanite or kyanite. The biotite-granulites of Coll seem to have originated from very impure sandstone rather than shale. In Tiree metamorphosed shale occurs, and is often richly garnetiferous, but, even so, it is abnormal owing to absence of muscovite.

The main minerals of the Coll sediments are quartz, felspars (never more basic than andesine), biotite (including phlogopite), pyroxenes (including diopside and hypersthene), amphiboles (typically pale-green), pink garnets, carbonates, forsterite (pseudomorphed), and calcic scapolite. Apatite and pyrites are the commonest accessories.

In the short descriptions that follow, very little attention can be paid to secondary changes. A general note is therefore given here on the common occurrence of prehnite in the paragneisses of Coll. In a very few slices, mentioned again in the sequel, prehnite builds considerable crystals or groups of crystals, probably in part replacing felspar and in part of independent formation. Prehnite with this habit occurs in a quartzo-calcareous sedimentary rock (21299) in the Clabhach Bay outcrop, and also in specimens (21306, 21310) representing xenoliths or xenolithic material picked up by the Ben Hogh granite-gneiss. In two of these slices (21299, 21306) the prehnite has another mode of occurrence, for it figures prominently in pseudomorphs after biotite, and it is in this fashion that most of the prehnite of Coll occurs. Typically it grows as a lenticle prising open the cleavage of the biotite, which may remain fresh but often passes to chlorite. The basal cleavage of the prehnite generally runs parallel with that of the biotite, but there is a strong tendency for the prehnite to form divergent growths. Good examples of prehnite wedging open biotite are afforded by (21317, 21323, 23284, 21387, 26298, 26300). In (21355, 21361) both prehnite and yellow epidote occur with similar habit and sometimes in actual association. There seems little doubt that prehnite is much more often developed in the calcareous sedimentary rocks of Coll than in the orthogneisses. Its formation probably dates from the Lewisian period and is unconnected with subsequent weathering.

Quartz-granulites.—Quartz-granulite, or quartzite, is developed on a very big scale in Ben Feall on the east side of Feall Bay. The outcrop is a quarter of a mile broad and the dip of the banding is eastwards at angles of about 45°. This banding is more regular than that of the grey orthogneisses, and may with confidence be considered as bedding, since the rocks in which it occurs are of sedimentary composition. There are variations of composition within the Ben Feall mass: most of it is somewhat felspathic, calcareous, and micaceous, while intercalated bands represent what were once calcareous or, more precisely, dolomitic shales. There is no better exposure for realizing, almost at a glance, that sediments enter largely into the Lewisian Complex.

Another exposure of quartzose granulite occurs in Hogh Bay immediately west of the mapped dark orthogneiss. In this case the outcrop is only 70 yds. broad, and has so pronounced a calcareous tendency that little of it is as quartzitic as the main mass of Ben Feall. Elsewhere in the disconnected exposures of Coll sedimentary types there are many bands of highly quartzose rock, but they are of small bulk.

The most quartzose types are represented by slices from Ben Feall (21376, 23291), from Hogh Bay (21315), and from Clabhach Bay (23290, 26299). Quartz is predominant, making more than half the material. Potash-felspar is a frequent associate, but plagioclase felspar is rare. Calcareous minerals, calcite, tremolite, or calcic scapolite (23290, 26299), are generally found. Muscovite and chloritized biotite are also common. The quartz usually occurs in exceedingly irregular grains measuring two or three millimetres across. In the scapolite-bearing slices the texture is coarser. Here somewhat rounded prisms of scapolite, up to 3 mm. long, and stout flakes of mica, generally of smaller size, lie in and among irregular quartz grains that may reach 15 mm. in length. The scapolite is sometimes very irregularly intergrown with oligoclase. In (23290) most of the mica is pale biotite; in (26299) it is muscovite. Other examples of scapolite-bearing rocks from Clabhach Bay, including analysed material, will be described presently under the heading quartzo-calcareous rocks.

Quartz-felspar-granulites.—Quartzose types rich in potash-felspar are represented by analysed material from the Ben Feall outcrop (Anal. III; 23026). In the hand the rock looks like a medium-grained, non-metamorphic sandstone of very pale pinkish tint. Under the microscope it appears as an equiproportioned mosaic of quartz and potash-felspar, in allotriomorphic grains generally measuring less than 1 mm. Much of the felspar shows microcline-twinning. Muscovite is an accessory, and one flake, moulded on other constituents, is 1 mm. long. The analysis agrees with the microscopic appearance. There is enough potash to combine with a third of the silica as potash-felspar, and this would account for almost all the alumina. Such a composition can easily be matched amongst arkoses. It can also be paralleled amongst igneous rocks, as is evident from Anal. B; but igneous rocks with more than 80 per cent. of SiO_2 (alaskites and ultra-acid porphyries) are rare and are generally of vein or dyke habit. The Coll specimen with its more quartzose and quartzo-calcareous associates is part of a great mass of bedded aspect, and may unhesitatingly be interpreted as of sedimentary origin. Specimens still richer in potash-felspar come from bands on the west of Crossapol Bay (21388, 21389). Plagioclase is present as perthitic intergrowths, or as independent crystals (oligoclase). Highly pleochroic biotite, and garnet, reddish-brown in the hand-specimen, are characteristic accessories. The oligoclase sometimes shows myrmekitic intergrowth with quartz (21388). It is doubtful whether such rocks can be distinguished lithologically from cross-cutting pegmatites in neighbouring exposures.

Quartzo-calcareous Rocks.—The analysed specimen (Anal. IV, 23025) from Clabhach Bay is shown by its composition to be a metamorphosed dolomitic sandstone. In the hand-specimen it looks like a rather fine-grained pale diorite. Under the microscope it is seen to be about half composed of quartz, while the remainder consists of pale-green amphibole and lime-scapolite, with accessory apatite. Individual crystals may be 3 mm. long, and the structure is markedly parallel but not banded.

Similar rocks can easily be collected at Clabhach Bay (21297, 26295, 26297, 26298, 26300). The main individual differences are due to presence or absence of diopside and biotite, and there is also doubt as to the interpretation of certain sericitic pseudomorphs, some of which may represent scapolite and others plagioclase felspar. Fresh lime-scapolite is well shown in (26298).

Quartzo-calcareous rocks from a little west of the Hogh Bay dark orthogneiss are represented by two slices. In one (21316) the main minerals are quartz and biotite with sericitic pseudomorphs almost certainly after scapolite; pale bluish-green hornblende also occurs. In the other (21317) quartz, biotite, potash-felspar, plagioclase, and lime-scapolite are all important constituents, the last two being mostly decomposed.

There are beds in the Ben Feall quartz-granulite series in which the chief minerals are quartz, diopside, and biotite, along with a certain amount of pale-green hornblende (21380, 21382). Cloudy apatite, pink in the hand-specimen, is a characteristic accessory. These rocks represent an approach to metamorphosed dolomitic shale, and are associated with quartz-free or quartz-poor analogues which will be described presently.

An unusual type from Clabhach Bay (21299) consists of quartz, pale-green amphibole, prehnite and accessory apatite, and a few grains of a mineral resembling zircon. The prehnite appears to be replacing both felspar and biotite.

Quartzo-felspathic Calcareous Rocks.—A small proportion of the quartzo-calcareous rocks are rich in potash-felspar. Presumably some of them were dolomitic arkoses in which the proportion of felspar to quartz has been increased during the formation of diopside or amphibole. In (21377) from the Ben Feall quartzitic outcrop, quartz is the most abundant mineral, but diopside, potash-felspar, and calcite are all well represented. In (21385) from Crossapol Bay, quartz is no more abundant than potash-felspar, while diopside accompanied by a little pale-green amphibole is dominant, and calcite is quite subsidiary. In (23292) from the outcrop mapped as marble east of Ben Feall, quartz and potash-felspar are accompanied by abundant tremolite associated with epidote.

It is impossible to decide in many cases how far the composition of the Lewisian rocks has been modified during their complicated history. For example, a specimen from a junction of marble and pegmatite, at the north end of Soa, consists mainly of potash-felspar and orientated biotite, with subordinate diopside and accessory blue apatite (23471). Similar extreme material comes from the calcareous belt mapped as marble east of Ben Feall (21373).

Marbles.—Probably half the sedimentary rocks of Coll are noticeably calcareous; but actual marble, though widely distributed, is restricted to occasional bands that perhaps never exceed 50 ft. in thickness. All the marbles are magnesian, like the analysed material (Anal. VI, 23028), from east of the square-walled garden half a mile east of Breachacha Castle, in which the main minerals are calcite, which makes about 55 per cent., forsterite, represented by serpentine pseudomorphs, and phlogopite. The two last are in about equal proportions, while apatite is a minor accessory. The pseudomorphs after forsterite occur as rounded grains, and the phlogopite as stout flakes, in each case 1 to 2 mm. long. The calcite builds allotriomorphic crystals up to about 3 mm. in length. The serpentine is of the very lowly birefringent type that usually replaces forsterite. The phlogopite is practically colourless, but is easily distinguished from muscovite by its uniaxial nature. All the three main constituents show clearly in the hand-specimen: the calcite as a white base, the serpentine as green translucent grains, and the phlogopite as glancing colourless flakes (*see also* 21364).

Closely similar marbles outcrop at Loch Gorton (21356, 21358, 23293, 23294) and south-south-west of Lonban (21313), also in the islands of Soa (21366) and Gunna (21399). Diopside is a fairly frequent mineral in these marbles and tends to segregate in nodules (21314, 21367). Tremolite is occasionally present; and one nodule or band consists of diopside grains enclosed poikilitically in crystals of pale bluish-green amphibole sometimes measuring 2 cm. across (21357). This last specimen contains conspicuous accessory apatite, very cloudy in thin slice and bright pink in the hand-specimen.

The phlogopite of the marbles ranges from colourless to pale-brown in thin slices. The coloured variety is best exhibited in a black and white marble from Gunna (21399). Here there occurs a black deposit, apparently magnetite, round several of the mica crystals and also round the serpentinous pseudomorphs after forsterite.

Diopside-amphibole Rocks.—We have mentioned the rather frequent occurrence of diopside nodules, sometimes with pale-green amphibole, in the Coll marbles. Similar material is common as thin beds associated with quartzo-calcareous or biotite-rich members of the suite. The diopside is usually very pale-green in the hand-specimen (medium-green in 21372) and has a granular felspathic appearance, with sufficiently marked cleavage to be easily distinguished from quartz. The amphibole tends to be darker, has a more elongated form, and shows its cleavage more conspicuously.

Under the microscope the diopside is nearly colourless, and the amphibole may be colourless or pale-green or, exceptionally (21372), fairly dark-green. Accessory minerals are quartz, felspar, and calcite. The main constituents are generally under 3 mm. in cross section, and, as a rule, build independent crystals.

Rocks of this character occur: in Clabhach Bay (21301, 21302); south of the Hogh Bay dark orthogneiss (21319, 21320); as a belt in biotite-granulite south of Rudha nan Uan (21323); in the outcrop mapped as marble east of Ben Feall (21372); and near the west end of Crossapol Bay (21386).

Biotite-rich Calcareous Bands.—Occasional thin dark beds intercalated in the Ben Feall quartz-granulite glitter with flakes of black mica, between which pale-green grains of diopside can be seen (21381). The mica under the microscope is brown and strongly pleochroic. Magnetite is an accessory. Incoming of quartz (21382) gives rise to a type of quartzo-calcareous rock already described.

Another specimen (21371) comes from the calcareous outcrop east of Ben Feall, in contact with dark orthogneiss. The hand-specimen shows twisted chlorite, after biotite, curving about little eyes of oligoclase. Under the microscope much pale blue-green amphibole is seen in stout crystals that sometimes have a colourless interior.

Non-calcareous Quartzose Biotite-granulites.—In the sedimentary series of Coll there are several pale bands, in which about half the rock consists of quartz and the remainder of felspar and orientated biotite with accessory apatite. Specimens come from Clabhach Bay (21298, 21300) and Gorton Bay (21355).

Biotite-granulite.—The rocks here grouped together as biotite-granulites are dark-grey, often unbanded, of rather fine texture, and conspicuously rich in orientated flakes of biotite which measure about 1 mm. across. The biotite is evenly distributed in a matrix mainly composed of oligoclase or andesine, which gives the whole a uniform granulitic texture, modified, of course, by the schistose orientation of the biotite. Quartz is present in variable proportions. Pink garnet, hypersthene, and green hornblende are often met with, though they are more commonly absent. Apatite and pyrites are frequent accessories.

This type makes up about a third of the bulk of the rocks for which a sedimentary origin is claimed in the Coll complex. If it stood alone its interpretation would be a matter of uncertainty, for its composition lies about the border line separating typical igneous rocks from typical sediments. The hornblendic members certainly occupy this indecisive chemical position, as has been proved by analysis of the most hornblendic material obtainable (Anal. V, 23027). In it the main mineral is andesine, accompanied by a fair proportion of quartz. Brown pleochroic biotite and distinctly green hornblende are both abundant. Apatite and pyrites are accessory. The chemical analysis shows that if the rock is igneous in origin it has an unusually low proportion of alkali for its 64 per cent. of silica. At the same time it can be matched in this and other respects among superior analyses of igneous rocks listed by Washington (*cf*. Anal. C). If, on the other hand, the rock is of sedimentary origin, it differs from typical argillaceous rocks in having: very little more alumina than would combine with its lime and alkalis to give felspar; less magnesia than lime; and less potash than soda. Accordingly it cannot be a metamorphosed shale, but, as comparison with Analyses D and E suggests, it may be a metamorphosed impure sandstone. The last interpretation is adopted because :—

(1) The analysed material must be considered along with its more normal associates that constitute the bulk of the Coll biotite-granulites. These are rich in biotite, free from hornblende, and in some cases garnetiferous (21324). They obviously have a composition much more readily interpreted as sedimentary than igneous.

(2) The biotite-granulites are an easily recognizable type in Coll, largely on account of their fine texture, so that their distribution is thoroughly known. With trifling exceptions, wherever biotite-granulite occurs, more obvious sedimentary types, such as various grades of quartzose and calcareous rocks, are also found. The association takes the form of apparent interbedding, and there are many intermediate passage rocks.

The best exposure of biotite-granulite lies west of Hogh Bay. Among specimens from this locality two (21321, 21322) contain biotite as their only ferromagnesian mineral; while the analysed sample already described (23027) carries biotite and hornblende; and another (21324), from near the orthogneiss on the south-west, biotite and garnet. In (21321) there is a considerable proportion of potash-felspar.

Biotite occurs without any other ferromagnesian in (21295) from the eastern limit of the Clabhach Bay exposures. It is accompanied by insignificant hornblende in two specimens (21397, 21400) from Gunna; and by a fair proportion of hypersthene and accessory garnet and hornblende in (21354) from Gorton Bay; and by abundant garnet and hornblende in a band beside the burial-ground on the west side of Crossapol Bay (21387). Other occurrences will be noticed later in describing the marginal relations of the ortho- and paragneisses.

THE ZONES AND THEIR MARGINAL RELATIONS

Zone 1.—The western grey orthogneiss has two outcrops, one on either side of Feall Bay. Exposures are good. Most of the outcrop consists of banded grey orthogneiss, with here and there intercalations of dark orthogneiss of sufficient importance to be shown on the one-inch Map. As already indicated the inclination of the banding of the orthogneiss in the outcrop west of Feall Bay is anticlinal, and in the eastern outcrop it is mostly isoclinal towards the east. Pegmatites are common, especially in Gunna.

Three minor occurrences of biotite-granulite or allied gneiss have been noted within Zone 1 :—

(1) A hundred yards within the boundary of Zone 1 there is exposed by the roadside west of Ballard, between Loch Breachacha and Hogh Bay, a narrow band of typical garnet-rich biotite-granulite. Its outcrop is about 30 yds. wide, and has been traced for 300 yds. along the strike as shown on the one-inch Map.

(2) Farther north, 500 yds. north-west of Totronald, and again about 100 yds. inside the boundary of Zone 1, there is a 3-ft. band of biotite-granulite.

(3) On the shore 70 yds. north-east of Dùn-beic, a third of a mile within the boundary of Zone 1, there is a 4-ft. band (21405) which differs from the adjacent grey orthogneiss (21404) in being richer in biotite and in carrying garnet in addition to hornblende. This apparently sedimentary band seems to end in lenticular fashion.

These intercalations are interpreted as enclosures in the igneous complex.

Marginal Relations of Zones 1 *and* 2.—The best exposure for examining the mutual relations of orthogneiss and paragneiss in Coll occurs half-way up the west shore of Crossapol Bay. The sedimentary rocks here are biotite-granulites often garnetiferous. Their main junction with the grey orthogneiss runs out to sea just west of Port an Duine (a locality named on the six-inch Map, Argyll 50 S.W.). Immediately north-east of this the coast-line takes a rather pronounced bend, and here, about 150 yds. within the boundary of the sediments, there occurs a band, some 20 yds. wide, of typical grey orthogneiss with layers and lenticles of hornblendic material. It can be traced along the sea margin northwards for 400 yds. until the garnet-biotite-granulite closes around its termination. This band envelops many thin layers and lenticles of the biotite-granulites, distinguishable from the hornblendic material already noted. They are commonly three or four inches thick, but occasionally less. There does not seem any room for doubt that the grey orthogneiss has invaded the granulite.

Specimens taken from this complex junction include (21390), a biotite-rich gneiss rather than granulite. It carries accessory garnet and represents the invaded sedimentary rock, quite possibly modified to some extent by absorption of igneous material. In (21393) from the tongue of invading orthogneiss, the mineral proportions are those of a typical quartz-oligoclase-biotite-diorite with very little orthoclase and accessory apatite. There can be no doubt of the igneous origin of such a rock. A dark lenticular inclusion proved on slicing to consist of green hornblende and hypersthene (21394). Two other slices (21391, 21392) taken from the invading orthogneiss rather suggest modification by digestion of sediment. In (21392) there is a considerable proportion of hypersthene.

Where the junction of Zones 1 and 2 reappears on the northern coast west of Feall Bay the same type of relations is hinted at without clear demonstration. There is a considerable belt of biotite-granulite, sometimes garnetiferous, sometimes hypersthene-bearing (21384), for which a sedimentary origin can safely be asserted. Within this are bands that exactly resemble grey orthogneiss, and one of them is indicated on the one-inch Map. It is probable that there has been considerable interpenetration of igneous material. Specimen (21383) illustrates what is regarded as a mixed sedimentary-igneous product. It is rich in biotite and big garnets, but has coarse igneous-looking quartzo-felspathic foliae.

Nothing of special interest has been noticed elsewhere along the junction of Zones 1 and 2.

Zone 2. In Gunna the prevalent paragneiss type is biotite-granulite. Some beds are calcareous, others quartzose. Magnesian marble occurs as thin intercalations in a dark orthogneiss band where exposed on the south shore. Some of the dark orthogneiss here appears calcified, and what has been interpreted as calcified grey orthogneiss occurs in two bands on the west coast of the island. The paragneiss series dips steeply southwards off the grey orthogneiss of Zone 1. Pegmatites are common, and on the west coast they are sometimes richly garnetiferous.

The same rocks are exposed with west-south-west strike in Eilean Bhoramuil. The skerries to the east, including Sgeir nan Garbhanach, are probably partly composed of Zone 2, but have not been visited.

On the west shore of Crossapol Bay the biotite-granulites appear again, where they are intruded by the associated grey orthogneiss of Zone 1 (*see above*). An excellent exposure of interbedded sedimentary types, mainly biotite and quartzo-felspathic granulites, both with garnets, is afforded by the shore near Crossapol burial-ground. Sometimes the garnetiferous quartzo-felspathic material has a cross-cutting (pegmatitic) relation. In the next 700 yds. to the east there are two other very good exposures of interbanded quartzose, biotite-rich, and calcareous material, cut at one place by a conspicuous pegmatite. Beyond this, for three quarters of a mile, the bay shows nothing but sand. Some of the hidden rocks come to view in the headland near Eilean Tunala. They are biotite-granulite, associated with calcareous quartz-granulite and cut by pegmatites, and are separated from the grey orthogneiss of Zone 1 by an important band of dark orthogneiss.

There is no exposure north of Crossapol Bay until the shores of Feall Bay are approached.

On the west of Feall Bay biotite-granulite is the main type, cut by white garnetiferous pegmatite and associated at its eastern side with a band of dark orthogneiss. It has already been pointed out that the separation between biotite-granulite and grey orthogneiss is not always clear in this exposure, probably a result of the intrusion of the latter into the former.

The head of Feall Bay is obscured by sand, but Ben Feall and the adjoining coast east of the bay furnish magnificent exposures. Ben Feall consists of a great mass of quartz granulite with minor intercalations of biotite-rich calcareous material. The whole has an impressive bedded appearance, with an easterly dip of about 45°. In this direction the quartz-granulite is succeeded by a highly calcareous series associated with dark orthogneiss. The latter is likely a continuation of the band already mentioned east of Crossapol Bay.

It will be seen from looking at the map that the exposures of Zone 2 in Crossapol Bay are sufficiently extensive to demonstrate that there is little but sedimentary material in the intervening sandy hollow. In Coll and Tiree it is the general rule that the orthogneisses are very fully exposed, while the paragneisses from their softer nature are largely concealed in sand-filled hollows.

If we return to Crossapol Bay we find at low tide that garnetiferous granulite is traceable round the southern termination of the dark orthogneiss that here separates the sediments of Zone 2 from the grey orthogneiss of Zone 1. The same garnetiferous granulite with pegmatites continues along the west shore of Loch Breachacha. Two thirds of the outcrop of Zone 2 is obscured by sand at the head of Loch Breachacha, where the only prominent exposure consists of an intercalated band of grey orthogneiss. The eastern boundary of the zone is, however, seen on the east shore of the Loch and at the Sgeirean nan Cuiseag end of the Soa group of islets. In the former locality calcareous rocks are involved with the Hogh granite-gneiss (Zone 3) in a manner that will be discussed presently. In Sgeirean nan Cuiseag there is a good exposure of marble and associated pegmatite.

Little need be said of the inland exposures between Loch Breachacha and Hogh Bay. They show that the median band of grey orthogneiss continues for at least two miles inland; and that as Hogh Bay is approached there is also a band of dark orthogneiss within the series. It is possible the latter is the same as the band or bands seen at the junction of Zones 1 and 2 west of Loch Breachacha and some little distance inside Zone 2 east of Ben Feall. Of the sediments themselves the two most interesting inland outcrops consist of marble. They are situated, the one beside the walled garden half a mile east of Breachacha Castle, and the other 300 yds. south-south-west of Lonban.

The coast section of Zone 2 west of Hogh Bay reads from west to east as follows (distances refer to width of outcrop measured across strike):—100 yds. of biotite-granulite with garnets near west margin, the whole flooded with white pegmatite; 20 yds. of highly calcareous rocks rich in diopside and amphibole; 350 yds. of biotite-granulite at Rudha nan Uan, cut by many white pegmatites; 70 yds. of calcareous quartzose rocks; Hogh Bay dark orthogneiss. Beyond the latter is scarcely an exposure till the margin of the Ben Hogh granite-gneiss, Zone 3, is approached.

Marginal Relations of Zones 2 and 3.—At the east end of the sand of Hogh Bay there is a small exposure of biotite-gneiss (21311). It resembles the sedimentary biotite-granulites, but is more coarsely crystalline and has quartzo-felspathic veins along the foliation which very likely have come from the Hogh granite-gneiss. The latter is seen a few feet away with its normal characters. In between is a zone of variable grey orthogneiss, which seems to interdigitate and at places to merge with its two neighbours. This border zone is strikingly xenolithic. Most of the xenoliths are dark in the hand-specimen and obviously composed mainly of hornblende. A slice (21309) shows a bluish-green hornblende of medium tint accompanied by quite subordinate quartz, apatite and pseudomorphs after biotite. Such a rock is more easily interpreted as of igneous than sedimentary origin. There are, however, a few xenoliths that certainly suggest derivation from a calcareous sediment. A slice from one of these (21310) shows two distinct crystallizations, a coarse-grained followed by a fine-grained. The main constituents with the coarse-grained crystallization are very pale-green amphibole, diopside, oligoclase, calcite, prehnite and quite subsidiary quartz. The diopside occurs in stout rounded prisms up to 3 mm. long enclosed poikiloblastically in the other constituents, among which the amphibole individuals sometimes measure 25 mm. across. In the finer crystallization we find small unorientated blades of tremolite and a little epidote partially replacing, in some cases along cracks, earlier calcite and prehnite. The matrix of the xenolithic layer may be normal Ben Hogh granite-gneiss (21308), but often the xenoliths are rolled out along with the matrix so that the unbanded granite-gneiss passes into a perfect example of a banded gneiss rich in ferromagnesian minerals such as rather pale-green hornblende with relics of diopside (21305–7). In one of the slices (21306) there are patches largely composed of prehnite, which presumably represent digested calcareous sediment.

Similar phenomena follow the boundary southwards and are best studied on the east shore of Loch Breachacha. Here, opposite the low-water termination of the sand at the head of the loch, a green xenolith was collected a little within the granite-gneiss. On slicing, it proved to consist of green diopside and medium-green hornblende with accessory biotite (21360). The colour was distinctly deeper than in most diopside-amphibole rocks collected from the Coll sediments, for instance (21357). At the same time this colour can be matched with that of a band or lenticle in the Soa marbles (21367). Now the Soa marbles, and also those seen at the walled garden inland from Loch Breachacha, belong to Zone 2 and lie just outside the Ben Hogh granite-gneiss, so that the xenolith is in all probability a calcareous sediment derived from Zone 2, modified possibly by absorption of magmatic iron. It is, however, right to state that diopside-hornblende rocks of similar composition do sometimes occur as plutonic igneous rocks.

On the one-inch Map the boundary of the Ben Hogh granite-gneiss is drawn as a firm line along much of the Loch Breachacha coast. The granite-gneiss continues with normal character (23285) to within a few feet of this boundary. It there merges into a grey flaggy series which is often highly calcareous and almost certainly in large measure of sedimentary origin. What is taken to be a reaction border along the edge of the granite-gneiss locally includes types characterized by abundant grains of green diopside (21363, 23283, 23284). Besides this mineral andesine is well represented with, in (21363), pale-green hornblende, biotite, and quartz, and in (23283, 23284) abundant potash-felspar, sometimes as large crystals. In these last two slices myrmekitic quartz is characteristic; in one of them (23283) there is accessory sphene and 'cauliflower' growths of diopside such as have been described above from certain apparently calcified orthogneisses (p. 13). It will be noted that this supposedly mixed rock from the shore of Loch Breachacha agrees approximately in mineral composition with certain varieties of augite-diorite and monzonite.[1] Two slices (21362, 21361), taken to illustrate the passage from this type into the normal Ben Hogh granite-gneiss, show progressive disappearance of diopside and deepening of the tint of remaining green hornblende.

Zone 3.—The great Ben Hogh granite-gneiss appears to be a single intrusion separating sediments, which now are spoken of as belonging to Zones 2 and 4. It forms the highest ground of the island (339 ft.) and everywhere exposures are excellent. Hornblendic xenoliths teased out and incorporated occur here and there but are a very minor feature. Some compact little xenoliths of andesine-biotite-rock are noteworthy on the coastal cliffs north-west of Ballyhaugh. Their foliation, shown in orientation of their biotite previous to crystallization of their andesine (21304, 22089), usually runs parallel with that of the surrounding granite-gneiss; but in several cases there is a marked discordance. These xenoliths are more felspathic than any of the sedimentary biotite-granulites outside the Ben Hogh granite-gneiss.

Marginal Relations, Zones 3 *and* 4.—At Clabhach Bay the marginal relations of the Ben Hogh granite-gneiss are obscured by shearing. At Loch Gorton they are hidden by sand.

Zone 4.—The Clabhach–Gorton sedimentary zone dips steeply off the Ben Hogh granite-gneiss in a curved outcrop convex to the east. This outcrop is about 100 yds. wide at Clabhach and 200 yds. wide at Gorton, and its length from coast to coast is 4 miles. Exposures at Clabhach Bay are mainly of calcareo-quartzose rocks, often containing scapolite. At one point these rocks show not only a crystallization parallel to banding, but also a cross-foliation developed parallel to the axes of little folds or crumples. Another feature of interest is a 15-ft. quartz-rock, which, as already mentioned, is considered to be a metamorphosed quartz vein, but is possibly a metamorphosed sandstone of exceptional purity.

Inland the sedimentary zone is generally covered, but it gives rise to a very definite hollow holding two fresh-water lochs. Here and there the quartz-rock is seen as indicated on the one-inch Map, and more locally small exposures of the undoubted sediments occur. The north end of Loch Cinneachan from west to east shows: calcareous quartz-granulite, some beds with pink garnet; dark hornblendic orthogneiss or schist; quartz-rock; biotite-granulite.

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[1] A previous record of norite-gneiss in this position was based upon a misnumbered slice.

Where the road crosses the outcrop at Acha the quartz-rock is thicker than elsewhere, measuring about 200 ft.

At the head of Loch Gorton an exposure of calcareous granulite, including an outcrop of marble, measures 20 yds. in width. South of this, towards the grey orthogneiss of Zone 5, biotite-granulite is encountered.

Marginal Relations of Zones 4 *and* 5.—At the eastern limit of the Clabhach Bay exposure of sedimentary rocks, biotite-granulite (21295) is cut by many pegmatites. Almost all of these are clean quartz-felspar pegmatites such as are commonly met with in biotite-granulite exposures elsewhere in Coll. One vein, however, has lenticular swellings which enclose veined augen of hornblendic rock in a manner characteristic of countless pegmatitic veins in the neighbouring grey orthogneiss of Zone 5.

Further evidence suggesting intrusion of the orthogneiss into the biotite-granulite is exposed at half-tide. Ten feet within the orthogneiss a 6-ft. band of biotite-granulite occurs. It can be seen that this band is impersistent, though the exact manner of its ending is hidden.

On the east side of Loch Gorton a junction-rock between biotite-granulite of Zone 4 and grey orthogneiss of Zone 5 is of gneissose texture, with oligoclase, biotite, and quartz as the main minerals, and garnet and pyrites as accessories (21353). The rock is probably an interaction product. There are occasional lenticles or bands of the same type within the neighbouring orthogneiss.

Zone 5.—Two thirds of Coll lie east of the Clabhach-Gorton line. In this area exposures are very good, though not continuous. There is a mosaic of peat and rock, the latter rising as a series of moundy hillocks without any particular orientation. The greatest height attained is 259 ft. The country rock almost everywhere is some variant of grey banded hornblende-biotite-orthogneiss. There are numberless bands and lenticles rich in hornblende, and there are also very many cross-cutting intrusions of pegmatite. Subordinate strips of pink acid gneiss occur, as, for instance, north of Eilean nam Muc on the east coast.

The banding runs in simple curves as indicated in Fig. 1. Dips are often quite moderate, as if due to open folding with a north-easterly pitch. South of Cliad Bay the banding is thrown into a very definite syncline.

An exceptional igneous type is exposed on the coast north of Meall na h-Iolaire. It is characterized by pink phenocrysts or porphyroblasts of microcline, measuring as much as 6 by 2 inches, set in a medium base of plagioclase and biotite with subordinate quartz. It is possibly a variety of pegmatite.

FLINTY CRUSH-ROCK

The term flinty crush-rock has come into general use among Scottish geologists to denote semi-vitreous products of crushing, characterized among other things by a flinty lustre. It would be out of place to treat the subject at length, but reference may be made to a few standard works by Clough, Holland, Dougal, Shand, Jehu and Craig, and Hall and Molengraaff.[1]

In Coll flinty crush-rocks are of insignificant proportions, but are fairly widely distributed. The gneiss of the coast-line north of Loch Eatharna is often shattered and sheared, and in such positions it is common to find little veins, some black and flinty in appearance, and others green and epidotic. Exceptionally individual veins may be as much as a foot wide, but more often they measure half an inch to two inches and have thread-like branches. On Eilean nam Faoileag a belt largely reduced to the condition of flinty crush-rock actually measures 15 ft. across Occasionally, as for instance, east of Loch Urbhaig, east of Arinagour, an obvious displacement can be detected along veins of flinty crush-rock ; but often all that is definitely clear is that the country rock has been intensely sheared along certain planes closely associated with the flinty veins. Viewed microscopically the crushing of the country rock is generally impressive (21403, 21420, 22144, 22145, 22153, 22160). Dark lines or zones of completely broken material come together at short intervals or cross one another. The dark and pale minerals are twisted and drawn out into lenses of broken material which are often waved. The quartz in early stages shows strain shadows. The final result may look little else than a dirty powder (22144).

Specimens were taken from two black veins of flinty lustre traversing relatively uncrushed gneiss 930 yds. south of Arinagour Pier. The veins are two inches thick. Thin sections (21421, 22154) show a certain amount of the ordinary evidence of crushing ; but they also reveal notable powdering, and many of the mineral fragments lie as though in a grit, the quartz without strain shadows, the biotite only slightly bent. Friction could not have produced such a powder, but shock of some sort, possibly connected with explosion, seems to be indicated. Professor Shand has already made this suggestion in regard to certain South African occurrences. The flinty veins in the present case are quite obviously in large measure glass with a detectable beginning of felsitic crystallization. A proportion of the quartz inclusions are rounded.

Flinty crush-rock has very seldom been noted in the northern half of Coll except along the east coast. It is possible indeed that the crush phenomena are connected with a fault which very probably flanks most of the south-eastern coast of Coll. Other evidence for such a fault is supplied by the steepness of the coast and the presence of deep water just off shore. Many hollows in the West Highlands have been eroded along shatter belts.

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[1] C. T. Clough *in* 'The Geology of the North-West Highlands of Scotland,' *Mem. Geol. Surv.*, 1907, *see* index ; T. Holland, 'The Charnockite Series, a Group of Archaean Hypersthene Rocks in Peninsular India,' *Mem. Geol. Surv. India*, vol. xxviii., 1900, pp. 108, 248 ; J. W. Dougal, 'Observations on the Geology of Lewis,' *Trans. Edinburgh Geol. Soc.*, vol. xii., 1928, p. 14 ; S. J. Shand, 'The Pseudotachylite of Parijs,' *Quart. Journ. Geol. Soc.*, vol. lxxii., 1917, p. 198 ; T. J. Jehu and R. M. Craig, 'Geology of the Outer Hebrides,' *Trans. Roy. Soc. Edinburgh* ; vol. liii., 1922, p. 430 ; vol. liii., 1925, p. 627 ; vol. liv., 1926, p. 483 ; vol. lv., 1927, p. 483 ; A. L. Hall and G. A. F. Molengraaff, 'The Vredefort Mountain Land,' *Verh. Konn. Akad. Weten. Amsterdam* (Tweede Sectie), deel xxiv., No. 3, 1925, p. 93.

On the other hand in southern Coll flinty crush-rock is developed more indiscriminately though still on a small scale. There is, for instance, a good example at Calgary Point, at the west end of the island. It is associated here and at other places in this part of the island with a sudden change in the strike of the country rock.

Mention has been made of epidotic crush-veins. The epidote is a green, feebly pleochroic variety (22150, 22159). It occurs as crowded crystals, some of which may reach 3 mm. in length. It is associated with exactly the same type of crushing of the country rock as has been noted above, in connexion with which the plagioclase is usually altered to albite and the ferromagnesian minerals decomposed. The epidote veins sometimes run along the crush zones and sometimes cross them, and they include fragments of the crushed material. Subsequent crushing sometimes breaks up the epidote itself. E.B.B., V.A.E., J.B.S.

CHAPTER III

MOINE SCHISTS OF ARDNAMURCHAN

INTRODUCTION

THE pre-Triassic rocks of the district included in the Memoir-map are all schistose and belong to the great series or complex known as the Moine Schists. Their most westerly exposure is near the Stone Circle (Greadal Fhinn), a quarter of a mile north-west of the head of Kilchoan Bay. This lies in Sheet 51 (the outcrop is shown on the Memoir-map but not on the one-inch Map). Otherwise all the schist exposures of the area fall within Sheet 52.

The Moine Schists throughout the district are metamorphosed felspathic sandstones, with quite subordinate micaceous partings representing shales. In spite of recrystallization their original sedimentary texture is very generally shown by the presence of comparatively large scattered grains of quartz and felspar. Their metamorphism increases markedly from west to east. So far as known the most lowly metamorphosed rocks are included in the biotite zone of Barrow's well-known classification; while most if not all of the country lying east of Ben Hiant belongs to the garnet zone.

It is generally supposed that the Moine Thrust passes near to the western end of Ardnamurchan, either obliterated by Tertiary intrusions or hidden under the sea. It appears, therefore, that the Ardnamurchan Moines decrease in metamorphism as they approach the Moine Thrust. A similar decrease has often been observed in the North-West Highlands. The possibility of mistaking the effects of crushing and retrogressive metamorphism for a true regional decrease of metamorphism has been carefully considered in the case of the grits and micaceous phyllites of the Kilchoan district. The conclusion has been reached that these rocks had never been highly metamorphosed.

The fall of metamorphism from east to west seems to be in large measure gradual; but the evidence suggests that it is also in part abrupt. If appearances on this score can be trusted, a thrust passes near the south end of Loch Mudle (exposures are not sufficient to allow of its precise location) and separates the Moine outcrop into two differently metamorphosed portions. West of this supposed thrust we have what may be called the Kilchoan Moines, less crystallized than the main mass of the Moines lying farther towards the east.[1]

Another aspect of the subject is illustrated in Fig. 2. On the two sides of a line which has been traced across Ardnamurchan in a general north and south direction past the south end of Loch Mudle, the attitude or structural disposition of the schists is markedly different, as is indicated in the letterpress of Fig. 2. This line does not correspond exactly with the boundary separating the Kilchoan Moines from the more crystalline rocks to the east—for instance, the exposures south-east of Ben Hiant seem all to belong to the eastern suite. It does, however, furnish an independent suggestion of thrusting in this vicinity.

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[1] *Cf.* C. T. Clough on the Tarskavaig Moines *in* 'The Geological Structure of the North-West Highlands of Scotland,' *Mem. Geol. Surv.*, 1907, p. 590.

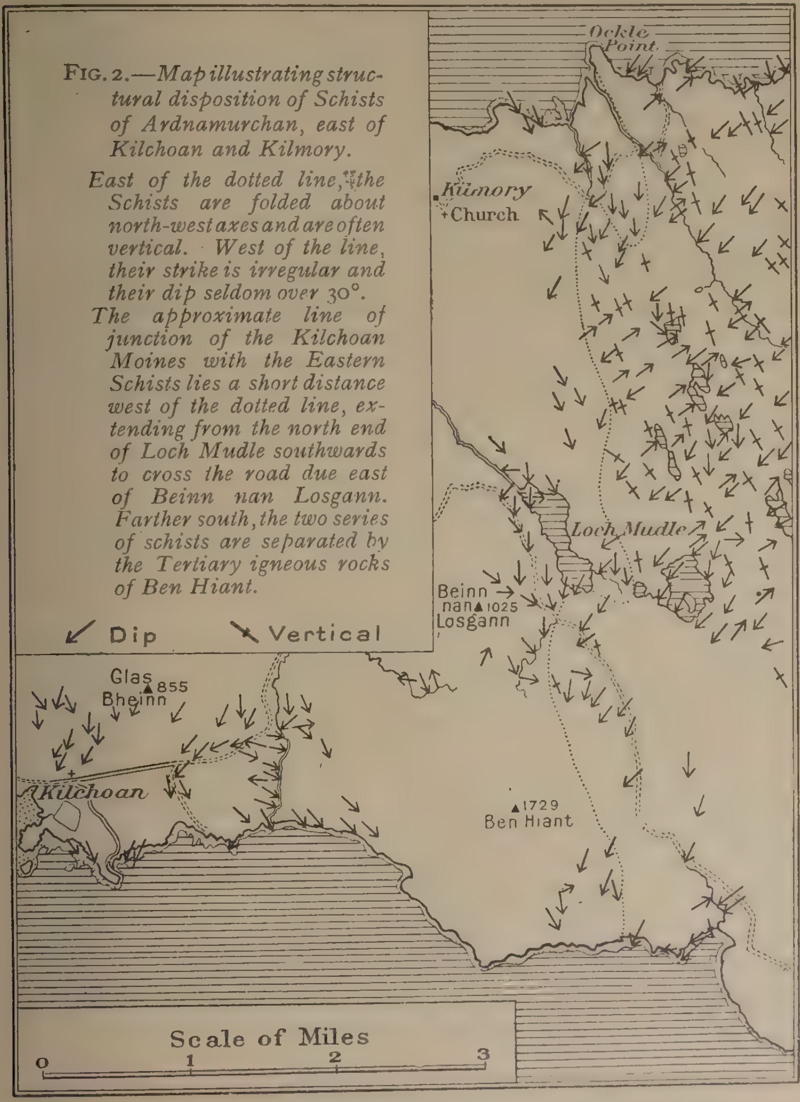

FIG. 2.—*Map illustrating structural disposition of Schists of Ardnamurchan, east of Kilchoan and Kilmory.*

East of the dotted line, the Schists are folded about north-west axes and are often vertical. West of the line, their strike is irregular and their dip seldom over 30°.

The approximate line of junction of the Kilchoan Moines with the Eastern Schists lies a short distance west of the dotted line, extending from the north end of Loch Mudle southwards to cross the road due east of Beinn nan Losgann. Farther south, the two series of schists are separated by the Tertiary igneous rocks of Ben Hiant.

E.B.B., J.E.R., J.B.S.

KILCHOAN MOINES

The type exposures, much complicated by Tertiary intrusions, occur between Kilchoan and the Ben Hiant vent. The rocks are sheared white recrystallized sandstones often somewhat gritty, and occasionally separated by thin grey phyllitic layers. Four specimens were sliced from the shore east of Glas Eilean. One (26742) represents the common type and roughly consists of two thirds quartz and one third alkali-felspar. It also contains scattered orientated flakes of muscovite, seldom 0·2 mm. long, and grains of iron-ore. Shearing and recrystallization mask the original grain structure of the quartz, but the felspar (predominantly microcline) has been very little deformed, and the larger grains up to 1·5 mm. are evidently essentially of sedimentary origin. The other three slices from this shore section (26294, 26741, 26745) have been cut from phyllitic partings. The first of the set is mostly made of wavy muscovite with embedded lenticular grains of quartz. Fresh brown deeply pleochroic biotite is fairly abundant and is undoubtedly a product of regional metamorphism. Some late-formed epidotic strings run along and across the foliation, and may possibly be of Tertiary date. The other two slices do not show any fresh biotite.

In three slices from inland exposures in this neighbourhood (26293, 26743, 26744), only the last contains fresh biotite, and this is in all probability contact biotite due to a neighbouring Tertiary intrusion. The other two, however, almost certainly contain pseudomorphs after regional biotite.

Another exposure assigned to the Kilchoan Moines is traversed by the road west of Loch Mudle. The supposed thrust-boundary of the Kilchoan Moines crosses the road due east of the summit of Beinn nan Losgann, and to the south more highly crystalline Moines are encountered. Four specimens have been sliced from the psammitic flags allotted to the Kilchoan Moines (26292, 23465–7). Of these, the first is noteworthy for the exceptional size, up to 6 mm. long, of some of its detrital grains of microcline. In (23465–6) fresh biotite occurs in minute flakes and there are also some very small partially chloritized garnets.

Crush phenomena (23613, 26291, 26746) were found in hillside exposures on the east side of Beinn nan Losgann, near what seemed to be the boundary between the Kilchoan Moines and the more crystalline schists; but it was not certain that the crushing coincided exactly with the position of the supposed thrust.

MORE CRYSTALLINE EASTERN MOINES

The easterly Moines are more massive in their outcrop than the Kilchoan Moines, and are pink rather than white, and they glitter with mica, while garnets are commonly seen in thin partings of mica-schist. Detrital grains of quartz and felspar are often recognizable. The only sliced representative of the main part of this area is a fine-grained muscovite-biotite-schist with very subordinate spongy porphyroblasts of garnet (24484).

As already stated, the Moines east of Loch Mudle have a very strong tendency to strike north-west. The dips are generally steep, either towards the south-west or north-east, and often pass through the vertical. It can be seen in various exposures, but more particularly on the north coast east of Ockle Point, that the rocks are thrown into a series of compressed folds of moderate dimensions and with steep axial planes directed north-west and south-east.

In the extreme north-east corner of the Memoir-map a different type is reached which has a broad outcrop farther to the east. The rock is still a metamorphosed felspathic sandstone, but is much more massive than the distinctly flaggy rocks hitherto described. On this account it gives rise to some of the barest rock scenery of the Highlands, whereas the other Moine rocks of the district disintegrate freely and are for the most part covered by grass. These massive Moines are highly crystalline, but retain particularly abundant and striking relict grains of felspar and quartz. Another feature is the perfection with which they have kept their original false-bedding. Three slices (21330–2) show scattered detrital grains of microcline and quartz up to about 3 mm. in length. The microcline has recrystallized marginally, while the quartz has granulitized into a mosaic of moderate dimensions. The matrix is a well-crystallized aggregate of quartz, alkali-felspar, muscovite, biotite, and epidote, in which the quartz tends to remain as separate irregular grains. E.B.B.

CHAPTER IV

TRIAS AND JURASSIC, ARDNAMURCHAN AND NORTH-WEST MULL

In North-west Mull, sediments underlying the Tertiary basalt lavas are exposed only on the west side of Bloody Bay. They consist of non-fossiliferous sandstones which are tentatively referred to the Jurassic (p. 49). In Ardnamurchan, on the other hand, Mesozoic sediments form outcrops of considerable extent, and range from Trias to the middle of the Jurassic, including Lias, Inferior Oolite and Great Estuarine Series. The area is traversed by innumerable minor intrusions injected into the Mesozoic strata and underlying Highland schists during the Tertiary volcanic period, and the disentangling of the Mesozoic geology is in many respects a difficult matter. Some fifty years ago the late Prof. Judd[1] elucidated the stratigraphical sequence with the aid of fossils and also through his recognition of the similarity of the lithological succession to that of neighbouring areas in the West Highlands. His main conclusions hold good, though the nomenclature has changed in certain particulars. For example, his Infra-Lias is now regarded as entirely Lower Lias and not in part Rhætic; while much of his Middle Lias has been transferred to the Lower Lias to agree with Woodward's scheme of classification. During the recent survey of Ardnamurchan perhaps the chief addition to our knowledge is the definite recognition of Upper Lias with Raasay Ironstone by means of zonal ammonites. Also, an interesting series of ammonites has been obtained from the lower portion of the Inferior Oolite, including a species hitherto unrecorded from the British Isles. Taken as a whole the area is, however, one of minor interest to the stratigraphical geologist, for its fossil-fauna is relatively sparse and the strata as a rule are considerably hardened by the Tertiary intrusions.

The general sequence together with that established in other districts in the West Highlands is set out in the table opposite, the thicknesses being in feet. The lithological description given of each group refers more particularly to the development in Ardnamurchan.

The main outcrops border the south and north coasts of Ardnamurchan, the more important of which are as follows. Trias and the Broadford Beds of the Lower Lias are well seen on the south coast east of Mingary Castle (Fig. 25, p. 177), and are also worth visiting near Swordle on the north side. At these localities the limestone has been worked in former days for lime. Along the west side of Kilchoan Bay, and for about a mile beyond, strata from the Pabba Shales up to the Inferior Oolite and Great Estuarine Series are well exposed, though the sequence is much interrupted and the beds are also a great deal indurated by minor Tertiary intrusions, chiefly cone-sheets (Fig. 3). It may be added that several considerable masses of Mesozoic sediments also occur within vents of Tertiary age, and that blocks of Inferior Oolite and Upper Lias found in the Achateny district on the north coast prove the former occurrence of these strata *in situ* in that neighbourhood.

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[1] J. W. Judd, 'The Secondary Rocks of Scotland. Third Paper. The Strata of the Western Coast and Islands,' *Quart. Journ. Geol. Soc.*, vol. xxxiv., 1878, pp. 686–722.

	ARDNAMURCHAN.	MORVEN.	S.E. MULL.	RAASAY AND SKYE.
JURASSIC—				
GREAT ESTUARINE SERIES (shales with *Estheria murchisoniae*)	upwards of 10	—	? 30	? 400
INFERIOR OOLITE (limestone and sandstone)	120	—	100	600–800
UPPER LIAS (black shales with unworkable Raasay Ironstone)	20	—	30	20–70
MIDDLE LIAS OR SCALPA BEDS (white sandstone)	about 40	—	200	240
LOWER LIAS—				
PABBA BEDS (sandy shales)	perhaps 400	160	400	600–700
BROADFORD BEDS (mainly limestone)	20–100	120	70	240
RHÆTIC	not found	? 10	not found	—
TRIAS (red sandstone, cornstone, breccia, and conglomerate)	0–20	330	thick	? 150

TRIAS

The presence in Ardnamurchan of Triassic strata, the Poikilitic of Judd, appears to have been first recognized by this investigator. These beds, however, are of small thickness. They include red sandstones and cornstones, with conglomerates and breccias that rest unconformably on the Moine Schists, and are succeeded by fine-grained basal Lower Lias limestones of the Jurassic (Judd's Infra-Lias). No fossils have been obtained from them, and their identification as Trias is based upon their general occurrence, here and elsewhere in the West Highlands, at the base of the Lias. In an exposure in Western Mull, it may be added, they are succeeded by a thin development of fossiliferous Rhætic.[1]

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[1] E. B. Bailey and G. W. Lee *in* 'The Pre-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1925, p. 64.

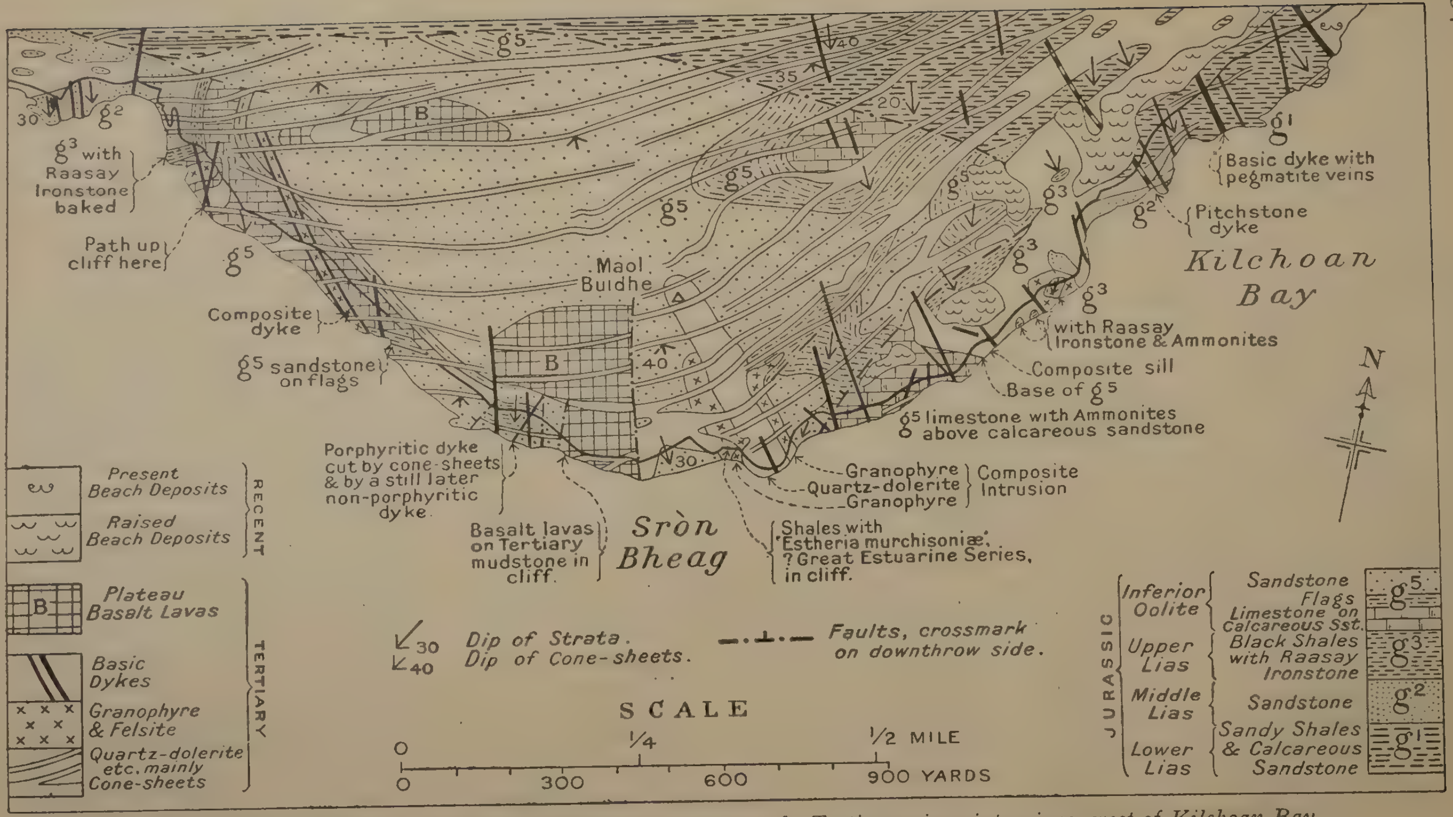
g5
40
35
20
B
g2
30
g3 with Raasay Ironstone baked
Path up cliff here
g5
Composite dyke
g5 sandstone on flags
Maol Buidhe
B
40
g5
g1
Basic dyke with pegmatite veins
g3
g2
Pitchstone dyke
Kilchoan Bay
g3
g3
with Raasay Ironstone & Ammonites
Composite sill
Base of g5
g5 limestone with Ammonites above calcareous sandstone
N
Granophyre
Quartz-dolerite
Granophyre
Composite Intrusion
30
Porphyritic dyke cut by cone-sheets & by a still later non-porphyritic dyke.
Basalt lavas on Tertiary mudstone in cliff.
Sròn Bheag
Shales with Estheria murchisoniæ. ?Great Estuarine Series, in cliff.
Present Beach Deposits
Raised Beach Deposits
RECENT
B
Plateau Basalt Lavas
Basic Dykes
Granophyre & Felsite
Quartz-dolerite etc. mainly Cone-sheets
TERTIARY
30 Dip of Strata.
40 Dip of Cone-sheets.
Faults, crossmark on downthrow side.
SCALE
0
1/4
1/2 MILE
0
300
600
900 YARDS
JURASSIC
Inferior Oolite
Sandstone
Flags
Limestone on Calcareous Sst.
g5
Upper Lias
Black Shales with Raasay Ironstone
g3
Middle Lias
Sandstone
g2
Lower Lias
Sandy Shales & Calcareous Sandstone
g1

FIG. 3.—*Map of Mesozoic strata and Tertiary basalt lavas cut by Tertiary minor intrusions, west of Kilchoan Bay.*

NOTE.—Tertiary cone-sheets are mainly represented diagrammatically.

The Ardnamurchan Trias is perhaps chiefly noteworthy on account of its cornstones. These chemically-formed limestones, deposited from solution, are at some localities found at the base of the Trias, and in this position they are seen to have permeated and partly replaced the underlying quartzose and felspathic schistose rocks in an intricate manner. The lime-bearing solutions have attacked the schists more especially along their bedding-planes, so that cornstone is found interleaving with these much more ancient rocks.[1] The conglomerates with well-rounded pebbles of white quartz are evidence of the abrasive action of water, and are a feature also of the Trias of neighbouring areas. In the sandstones no wind-rounding of sand grains was noted.

In the south-east part of the Ardnamurchan area, Triassic rocks are absent and the Lower Lias overlaps directly upon the schists. A good section is exposed 350 yds. south-east of Mingary Castle, where the island of Rudha a' Mhìle, connected with the mainland at low tide, is largely composed of Trias (*see* Fig. 25, p. 177). Junctions with the Moine Schists are well seen and a basal breccia mainly consists of these underlying rocks. Similar beds of breccia reappear at higher levels, interbedded with red sandstone and cornstones. Altogether the Trias is here less than 20 ft. thick. Its relation to the succeeding Lias limestone is clearly exposed at the base of a stack at the south end of the island, the upper portion of which is formed of a Tertiary quartz-dolerite sill. The upper limit of the Trias is drawn at the top of a bed of pebbly sandstone, which is succeeded by 6 ft. of white sandstone and sandy limestone that are included with the Lower Lias. At the north-west end of the island the junction of Trias and Lias is again exposed. A cornstone there occurs at the top of the Trias, and is succeeded by similar Lias strata to those just cited.

Three quarters of a mile eastwards of Mingary Castle, in cliffs bordering the 25-ft. Raised Beach, cornstones are well seen at the base of the Trias and permeate the underlying Moine Schists. The same phenomena are also met with half a mile west of Mingary Castle, to the south-east of Kilchoan, a few yards south-west of the office-house at Mingary Pier (Fig. 23, p. 174).

In the Ben Hiant district, Triassic strata a few feet thick are exposed at various localities. For instance, schist-breccia rests on the schists near the shore west of the great quartz-dolerite mass termed the Ben Hiant Intrusion, while quartz-conglomerate, schist-breccia, red sandstone and cornstone are exposed in streams on the south-east side of the hill. J.E.R.

Farther east, south-east of Loch Mudle, around the margins of an extensive outcrop of Tertiary basalt lavas, the Trias may be everywhere absent. At the northern end of the lava-outcrop its absence at the base of the Lias is in fact demonstrable (p. 40), though immediately to the north, in a stream flowing between Lochan a' Mhadaidh Riabhaich and Loch Mudle there is a small expanse of purplish cornstone. Along the eastern side of the outlier, only partly included in the Memoir map, thin sandstone and conglomerate frequently separate the lavas from the schists, but have been tentatively assigned to the Tertiary (p. 105). A 6-ft. calcareous sandstone seen below the lavas on the foreshore west of Ardslignish farm is probably Mesozoic, either Trias or Lias. J.B.S.

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[1] For other Triassic examples of the same phenomenon *see* E. B. Bailey *in op. cit.*, p. 70, and A. Heim, Geologie der Schweiz, Band II, 1920, Fig. 50, pp. 159, 160. Similar partial replacement of schist by limestone occurs at the base of cornstone of Upper Old Red Sandstone (or Carboniferous) age at Loch Ranza in Arran. *See* W. Gunn *in* 'The Geology of Arran,' *Mem. Geol. Surv.*, 1928, p. 47.

Near the north coast about 20 ft. of breccia, conglomerate and sandstone are seen at several places between the Lower Lias and the Moine Gneiss. The material of the breccias and conglomerates is generally a calcareous sandstone or grit, and the pebbles consist of the local gneiss, often but slightly rounded. Exposures are sufficiently numerous along the mapped outcrops, and attention need only be drawn to a type example a little above the mouth of the stream that flows past Ockle. E.B.B.

JURASSIC

LOWER LIAS: BROADFORD BEDS AND PABBA BEDS

(HETTANGIAN, SINEMURIAN, AND CHARMOUTHIAN)

H. B. Woodward's designation 'Broadford Beds'[1] applies to the lower, mainly calcareous division of the West of Scotland Lower Lias, and may be used here conveniently, since some of the chief features of the type district of Broadford in Skye are present in Ardnamurchan. The principal departure from type is the absence of the Ostrea Beds so fully represented in Raasay, Applecross, and Skye. But, since oyster beds depend on definite physical conditions for their formation, the Ostrea Beds of the districts mentioned above may be represented here in point of time by part of the lowest layers succeeding the Triassic cornstones. The gap above the Trias cannot, therefore, be proved to involve much more than the *Pteria contorta* Zone of the Rhætic.

The term 'Pabba Series' was introduced by Judd to denote the thick series of sandy shales which, according to Woodward's more recent classification, constitute the higher member of the Hebridean Lower Lias. Judd himself treated these Pabba Beds as forming the lower member of the Middle Lias.

In Skye, the Oxynotus Zone is absent, and all Liassic strata below this level have been grouped with the Broadford Beds, while the higher beds of the Lower Lias have been placed in the Pabba Beds.[2] This grouping agrees with the lithology, except that the top of the Broadford Beds as thus defined consists of shales.[3]

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[1] H. B. Woodward *in* 'Ann. Report of Geol. Survey for 1896,' *Mem. Geol. Surv.*, 1897, p. 70.

[2] C. B. Wedd *in* 'The Geology of Glenelg, Lochalsh and South-east Part of Skye' (Explanation of one-inch Map 71), *Mem. Geol. Surv.*, 1910, p. 98.

[3] *Ibid.*, p. 106.

In Ardnamurchan the same classification is adopted with the qualification that the Oxynotus Zone, which seems to be represented, is placed with the Pabba Beds. Here again, and also in the neighbouring district of Morven, the shale-development begins near the top of the Broadford Beds. On this account, in the Memoir dealing with Mull and Morven,[1] the Birchi and Obtusus Zones were classed with the Pabba Beds. It is, however, thought better in the present Memoir to adhere to the palæontological definition as applied in Skye, the type district.

In the following zonal table, which includes the zones identified in Mull and Morven (Loch Aline) as well as in Ardnamurchan, it will be seen that the 'Semicostatus' Zone is retained, though, as Dr. Spath[2] has pointed out, *Arnioceras semicostatum* is now known to belong to the overlying Birchi Zone. The term 'Semicostatus' Zone is here retained, within inverted commas, for convenience of comparison with previous literature. All the ammonites mentioned in the text were identified by the late Mr S. S. Buckman.

ZONES.	SHEETS 51 & 52.	SHEET 44.		SHEET 43.	SHEET 52.	STAGES.
	ARDNAMURCHAN.	MORVEN.	S.E. MULL.	W. MULL.	N. MULL.	
PABBA BEDS						
Capricornus ..			?			CHARMOUTHIAN.
Ibex					x	
Jamesoni ..			x			
Armatus ..			x			
Raricostatus ..			x			
Oxynotus ..	?					SINEMURIAN.
BROADFORD BEDS						
Obtusus ..	x	x				
Birchi		x				
'Semicostatus'	x	x	x			
Bucklandi ..	?	x				
Rotiforme ..		x				HETTANGIAN.
Angulatus ..	x		?			
Planorbis ..	x			x		

Broadford Beds.—In the southern part of Ardnamurchan the lowest Liassic beds, the age of which is indicated by palæontological evidence, consist of a few feet of hardened shales and thin beds of compact limestone on the shore just south of Mingary pier at Rudha Àird an Iasgaich, south of Kilchoan. The pier itself stands on Trias (Fig. 23, p. 174). The Lias here has yielded *Ostrea sp.*, *Mytilus ?* and '*Cypricardia*' *perrecta* Dum. The latter is a species which belongs in the Rhone Basin to the Planorbis Zone.[3] Although the actual zonal fossil *Psiloceras planorbis* (J. de C. Sow.) was not found, there can be little doubt that these beds are in or about the Planorbis Zone. It might be mentioned here that, in Scotland, the shaly facies of the Planorbis Zone, with its index ammonite, is known so far only in Western Mull[1] and as blocks in a volcanic neck in Arran.

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[1] G. W. Lee *in* 'The Pre-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1925, p. 75.

[2] L. F. Spath, 'On Lower Lias Ammonites from Skye,' *Geol. Mag.*, vol. lix., 1922, p. 171.

[3] E. Dumortier, 'Etudes paléontologiques sur les Dépôts jurassiques du Bassin du Rhône,' 1864, Part i., Pl. vi., Fig. 4.

The beds just referred to are possibly represented in No. 5 of the following section measured by Mr. Richey near the southern extremity of Rudha a' Mhìle, Mingary :—

	Ft.	In.
6. Blue granular limestone	5	0
5. Pale compact limestone with partings of shale ..	5	0
4. Sandy shale	0	6
3. Compact limestone	2	0
2. Sandy limestone with white sandstone at base ..	12	0
1. Yellow cornstone (TRIAS).		

Modiola hillana, J. Sow., *Cardinia sp.* and *Pleuromya sp.* were obtained from the shales and sandy limestones. The *Pleuromya* is characterized by the nearly central position of the umbones, and is like a form represented in the Jermyn Street Museum by specimens from the Bucklandi Zone.

On the shore, north of Rudha a' Mhìle, compact white limestones and dark shales are faulted against Trias near high-water mark (Fig. 25, p. 177), and have yielded a fauna which although scanty seems to indicate a higher horizon. It consists of a Rhynchonellid, possibly new, a form suggesting a young specimen of *Lima gigantea*, a gryphaeate *Ostrea*, a large-ribbed *Ostrea* and a *Pecten*, probably undescribed, recalling *P. valoniensis* Defr. by its shape, but with finer ornamentation, specially on the ears. The ribbed *Ostrea* is of the group of *O. arietis* Quenst., and may be allied to an unnamed form from the Angulatus Zone figured by Dumortier.[2] This, together with the gryphaeate *Ostrea* and the *Lima*, would point to the top of the Hettangian, that is, either the Angulatus Zone or just above it.

Honeycomb-weathering limestones which are seen on the shore east-south-east of Mingary Castle are characterized by the abundance of *Gryphaea arcuata* Lam. of the large, narrow, strongly incurved type, with sulcus. The Gryphaea Limestones have not yielded any ammonites, but an upper limit to their age may be inferred from the fact that stratigraphically higher beds in the vicinity of Mingary Castle, consisting of flaggy shales, chiefly belong to the 'Semicostatus' Zone, though perhaps also including the top of the Bucklandi Zone.

Dark blue flags, that probably immediately succeed the Gryphaea Limestones, are exposed in disconnected outcrops partly enveloped by a Tertiary basic sill on the shore near low-water mark 250 yds. east-south-east of Mingary Castle (*see* Fig. 25). Ammonites there predominate largely over other fossils, as shown by the following collection made by Mr. Manson :—

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[1] G. W. Lee *in* 'The Pre-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1925, pp. 86–88.

[2] E. Dumortier, *op. cit.*, Pl. xxiii., Fig. 6.

Rhynchonellid, new
Lima (Plagiostoma) gigantea (*J. Sow.*) [*cf.* young of]
Agassiceras *cf.* subtaurus (*Reynes*)
,, *cf.* terquemi (*Reynes*)
Arnioceras *cf.* acutidorsale *Hyatt*
,, *cf.* bodleyi *J. Buck.*
,, *cf.* dimorphum *Parona*
,, *cf.* elegans *Fuccini*
,, *cf.* falcaries (*Quenst.*)
,, fortunatum *S. Buck.*
,, *cf.* hartmanni (*Oppel*)
,, *cf.* incipiens *Hyatt*
,, *cf.* kridiforme *Hyatt*
,, *cf.* mendax *Fuccini*
,, munitum *Fuccini*
Asteroceras *cf.* undaries (*Quenst.*)
Cymbites *cf.* lævigatus (*Reynes*)

This list indicates a possible equivalence with Dr. Spath's[1] 'bed full of *Arnioceras*' (base of 'Semicostatus' Zone or top of Bucklandi Zone), though Buckman pointed out that the presence of *Asteroceras* suggests a much later date.

The Gryphaea Limestones are in faulted contact with higher beds consisting of dark flaggy shales with calcareous nodules which belong, according to Buckman, to the Agassiceras horizon (upper part of 'Semicostatus' Zone). The fault is seen on the shore 50 yds. east-south-east of Mingary Castle, just west of which Mr. Manson obtained the following from the flaggy shales:—*Piarorhynchia* cf. *radstockiensis* (Dav.), *Piar. sp.*, cf. *P. triplicata juvenis* (Quenst.), *Spiriferina walcotti* (J. Sow.), *Agassiceras* cf. *halecis* (J. Buck.), and another ammonite, possibly belonging to a new genus, but resembling *Xipheroceras scoresbyi* (Simpson). The presence of such a form is strange, since Buckman pointed out that a *Xipheroceras* should be very much later than *Agassiceras*.

On the shore south-west of Mingary Castle and below the sill on which the castle stands, hardened flags and shales have yielded a fauna which, according to Buckman, is somewhat later than that just considered, though probably still of *Agassiceras* date.

Piarorhynchia *cf.* triplicata juvenis (*Quenst.*)
,, *cf.* radstockiensis (*Dav.*)
Rhynchonellid, new ?
Spiriferina walcotti (*J. Sow.*)
Zeilleria "perforata" *Auctt.*
Pecten liasinus *Nyst.*
Arnioceras, *between* A. miserabile *and* A. spirale *Fuccini*
,, *cf.* mendax *Fuccini*
,, *cf.* spirale *Fuccini*
Cymbites sp.

According to Dr. Spath[2] still higher beds, with *Arietites* (Obtusus Zone), occur at Mingary Castle, but representatives of that genus have not been met with by the Survey. G.W.L.

Inland, alongside a cross-country track north-east of Beinn na h'Urchrach and in two neighbouring streams, the Broadford Beds lie at 700 ft. above sea-level. The following section has been estimated beside the path :—

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[1] L. F. Spath, 'On Lower Lias Ammonites from Skye,' *Geol. Mag.*, vol. lix., 1922, p. 175.

[2] L. F. Spath, *op. cit.*, p. 172.

	Ft.
Blue granular limestone	25
Pale compact limestone	30
Sandy limestone and calcareous sandstone ..	10

A bed rich in *Gryphaea arcuata* is exposed below the track shown on the Memoir-map in the more easterly of the two streams. In the more westerly stream, Pabba shales occur, but the section is discontinuous.

At the northern extremity of the outlier of Tertiary lavas, to the south-east of Loch Mudle, the Broadford Beds are seen resting on schist and overlain by shales (? Pabba Beds). They consist of 25 ft. of limestone with a basal bed of fine white sandstone. As at Rudha a' Mhìle, near Mingary Castle (p. 38), the basal white sandstone is overlain by sandy limestone that forms a link with the succeeding typical Lower Lias limestone. J.E.R.

Along the north coast, near Swordle, the Broadford Beds reach their maximum thickness for Ardnamurchan, about 100 ft. They everywhere rest on Trias and are seen covered by Pabba Beds in a road section. At Ockle Point, about 10 ft. of sandy beds, including dark calcareous sandy shales, form the actual base of the group. The limestones are less split up by shale partings than is usual. Fossil fragments are often conspicuous but it is difficult to obtain good specimens. Dr. Lee, in the field, saw specimens which he referred to *Lima gigantea*, *Ostrea*, and *Modiola*. At one locality, the coastal cliff shows several courses of calcareous shale crowded with *Gryphaea arcuata*. This locality is situated 300 yds. east of a great Tertiary vent, immediately east of a small gorge that has been eroded along a fault. E.B.B.

From the 10 ft. of sandy beds at Ockle Point at the base of the series Mr. Manson succeeded in extracting specimens which may be doubtfully referred to *Modiola hillana* J. Sow. and to *Perna infraliassica* Quenst. This would indicate an horizon either in the Hettangian or low down in the Sinemurian. A poorly preserved coral found on the west side of Garbh Rudha, three quarters of a mile north-east of Kilmory, may belong to *Thecosmilia martini* de From., which in its best Scottish locality, viz. Applecross, is a form belonging to the top of the Hettangian.

The *Gryphaea arcuata* mentioned above belongs to the typical strongly incurved form. A few other fossils were obtained from the same locality. They are :—*Modiola sp.*, *Ostrea* cf. *liassica* Strick., *Pecten liasinus* Nyst., *P.* cf. *textorius* (Schloth.), and *Pinna hartmanni* Zieten.

Fossils were collected by Mr. Manson from dark shales and calcareous flags in the volcanic vent on the shore half a mile north of Kilmory. They are :—

? Piarorhynchia *cf.* radstockiensis (*Dav.*)
Aria ?
Gresslya ?

? Homomya sp.
Lima hettangiensis *Terq.*
Ostrea ?
Pecten sp.
Pleuromya sp.
Pteria sp.
Cymbites *cf.* laevigatus (*Regnès*)

Buckman referred the specimen of *Cymbites* to a position about the *Agassiceras* horizon (top of ' Semicostatus ' Zone). G.W.L.

Pabba Beds.—These beds consist mainly of sandy, well-bedded shales, containing scattered flakes of white mica. They are thicker than any other group in the Jurassic of Ardnamurchan. Elsewhere in the West Highlands the Pabba Beds are often richly fossiliferous, but this does not hold good in the present area, though on the west side of Kilchoan Bay, along almost a mile of coast, they are well exposed. They there dip obliquely to the shore line, and extend inland and westwards in a broad outcrop, to meet the coast again west of the headland of Sròn Bheag. Their thickness may be estimated as about 400 ft., and along Kilchoan Bay the following succession may be seen.

	Approximate thicknesses in ft.
Base of MIDDLE LIAS Sandstone	—
6. Flaggy, micaceous, sandy shales with encrinites, and calcareous sandstone bands with belemnites	50
5. Calcareous sandstone with belemnites	0 to 25
4. Sandy shales with encrinites; shales with calcareous nodules, containing belemnites, large pectens, etc.	100
3. Sandy flaggy shales, with *Gryphaea* of *obliquata* type	100
2. Sandstone	25
1. Sandy shales and fine-grained fissile shales (Base of PABBA BEDS)	100
	400

The basal beds, that succeed the Broadford Limestones, consist of greenish-grey shales, fissile and fine grained. They are, so far as known, devoid of fossils. The shales may be seen in stream-sections north and north-east of Ben Hiant, east of Beinn na h'Urchrach, as well as along Kilchoan Bay.

The shales extending inland and westwards from Kilchoan Bay are considerably baked by Tertiary intrusions, but indications of their identity with the Pabba Beds of the shore-section may be observed at various points. On the hillside south-east of two small lochs, south-east of Beinn na Seilg, calcareous nodules and also traces of large belemnites can be detected, the latter white and chalky in aspect owing to their baked condition. They resemble subdivision 4 of the succession tabled above. Traces of calcareous nodules in highly baked shales can also be seen near to the margin of the Tertiary gabbro east of a valley east of Dubh Chreag. On the summit of Dubh Chreag, next to the gabbro, a highly baked limestone emerges from beneath the thick contact-hardened shales, and may confidently be referred to the Broadford position. Where the baked Pabba Beds again reach the shore, south-west of Beinn nan Codhan, they contain a bed of *Gryphaea*. This locality is somewhat difficult to reach as the coastal slopes are steep. The shell-bed occurs on the north side of a small inlet, 200 yds. east of the Tertiary gabbro.

Two other localities for Pabba Beds have already been mentioned in the descriptions of the Broadford Beds south-east of Loch Mudle, and in the road west of Swordle. More extensive exposures occur on the north coast, west of Faskadale, in the neighbourhood of Rudha Groulin. The strata are very highly baked, but a lithological succession can be established which includes micaceous sandy shales (Pabba Beds) underlying white fine-textured sandstone (Middle Lias). J.E.R.

The state of preservation of the few fossils obtained from Ardnamurchan is so poor that there is little of palæontological interest to be mentioned. The most common fossil is *Gryphaea*, which is represented by *G. cymbium* Lam. and forms intermediate between it and *G. obliquata* J. Sow. Belemnites appear to be next in order of abundance; among these *B.* cf. *apici-curvatus* de Blainv. and *B. clavatus* de Blainv. were recognized. Of lamellibranchs (other than *Gryphaea*), *Cardinia sp.*, *Pecten acuticostatus* Lam., and a small *Pecten* of *aequivalvis* type are all that was obtained. A single ammonite was found, on the shore below Ormsaigbeg, Kilchoan; Buckman was not able to determine it, but he suggested that it may be referred to *Gagaticeras*. If of that genus, the Ormsaigbeg section would then fall within the Oxynotus Zone.

In South-east Mull, Skye, Pabba, and Raasay, the top portions of the Pabba Beds are conspicuously fossiliferous, ammonites being specially abundant, and since baking does not completely obliterate all traces of fossils, it would seem probable that in Ardnamurchan parts of the higher Pabba Beds may have been cut out by faulting. On the other hand, no fault has been found in the required position on the west shore of Kilchoan Bay. G.W.L.

MIDDLE LIAS: SCALPA SANDSTONE

(DOMERIAN)

In Ardnamurchan, this group is of little interest, for it consists of only some 30 to 40 ft. of sandstone, in which no fossils have been found. The sandstone is white, fine-grained and well-bedded, sometimes false-bedded. In the only complete outcrop, on the north coast two thirds of a mile east of Rudha Groulin, the sandstone passes gradually downwards, by intercalation with layers of sandy shale, into the Pabba Shales; it is separated from overlying fissile, dark shales, which are evidently of Upper Lias age, by transition beds consisting of sandy shales. The beds are much baked, and no fossils have been found in them, but the lithological succession leaves no doubt as to their stratigraphical positions.

On the west coast of Kilchoan Bay, the Scalpa Sandstone can be recognized in a few disconnected outcrops amongst Tertiary cone-sheets and sills, which intervene between Pabba Shales and fossiliferous Upper Lias. Farther west, around the head of a small bay south of Dubh Chreag, the sandstone is again well seen in coastal cliffs, and appears to be thicker than at other localities mentioned. Along the east side of this little bay, it is directly overlain by the fossiliferous Upper Lias shales; whilst inland to the north it is faulted against the Pabba Shales.

UPPER LIAS

(YEOVILIAN–WHITBIAN, in part)

The Upper Lias consists of fine-grained, fissile shales, purplish-black in colour, together with a seam of limy ironstone, which is correlated with the Raasay Ironstone. These strata are of considerable interest, though their total thickness is no more than 20 ft. A number of ammonites have been collected from both shales and ironstone.

The chief fossiliferous exposures are along the west shore of Kilchoan Bay, 1500 yds. south-west of the Landing Jetty, and just beyond a slight headland formed of a plexus of Tertiary basic intrusions (Fig. 3). The black shales occur in lenticular masses, a few yards long, amongst a complex of basic cone-sheets and sills. In two of these, the limy ironstone is exposed. The seam is a bluish, compact stone, largely composed of ooliths. In this character it resembles the Raasay Ironstone, but its thickness is less, being not more than 4 ft. in Ardnamurchan. A mile farther west, south of the angle of the bay south of Dubh Chreag, fissile shales that overlie the Scalpa Sandstone contain a 4-ft. bed of oolitic ironstone with belemnites, which is without doubt the same seam as that just mentioned. It is exposed at low tide with shales in contact above and below, and lies 7 ft. above the top of the Scalpa Sandstone, and 9 ft. below the apparent base of the Inferior Oolite. The strata are here greatly baked by the Tertiary gabbro, and the ironstone is converted into magnetite. In consequence, no fossils other than the belemnites in the ironstone have been obtained from these strata. Their reference to the Upper Lias is, however, unquestionable, for they agree, apart from metamorphism, in rock-type and also in stratigraphical position between a sandstone group (Scalpa Sandstone) and an overlying thick limestone (Inferior Oolite). The outcrop affords the only complete section in Ardnamurchan of the Upper Lias. An exposure of fossiliferous, fissile shales, 200 yds. west by north of Kilchoan Established Church, also belongs to the Upper Lias. J.E.R.

The indurated shales along the west shore of Kilchoan Bay, mentioned above, have yielded:—

cf. Stolmorhynchia sp.
? Pseudomonotis substriata (*Zieten*)
Dactylioceras *cf.* angulatum (*J. Sow.*)
,, *cf.* annuliferum (*Simpson*)
,, *cf.* commune (*J. Sow.*)
,, *cf.* holandrei (*d'Orb.*)
,, sp.
Harpoceras *aff.* falciferum (*J. Sow.*)
Belemnites sp., *elongate form.*

On the whole, these species indicate the Falcifer Zone.

The shales from the exposure 200 yds. west by north of Kilchoan Established Church are of the same age, and they contain :—

Inoceramus dubius *J. de C. Sow.*
Pecten (Amusium) *cf.* paradoxus *Goldf.*
Dactylioceras *cf.* holandrei (*d'Orb.*)
,, *cf.* raristriatum (*Quenst.*)
,, sp.
Harpoceras *aff.* falciferum (*J. Sow.*).

In addition to these Mr. Manson obtained a fragmentary impression of an ammonite which suggests a likeness to *Dumortieria meneghinii* Zittel (in Haug). But Buckman has pointed out that if this '*Dumortieria*' is to be dated with other members of its genus, then it must be considerably post-*striatulum* in date, a conclusion which seems difficult to accept.

As already mentioned the ironstone at the first locality is fossiliferous, its fauna consisting of Cephalopods, which are :—

Alocolytoceras *cf.* perlaeve (*Denckm.*)
Dactylioceras *cf.* holandrei (*d'Orb.*)
Grammoceras *aff.* penestriatulum *S. Buck.*
,, *aff.* toarciense (*d'Orb.*)
? Phylloceras sp. [or perhaps *Paroniceras*]
Belemnites sp., *conical form*
,, sp., *cylindrical form*

There is also in the collection a new ammonite, which Buckman was unable to place. The above list is of great interest as regards the light it throws on the age of the Raasay Ironstone. The fossils found in the ironstone of the type district are derived,[1] the latest indicating *Subcarinatum*-time, or a little later, as presumed date of deposition. Here, the *Alocolytoceras* and the *Grammoceras* indicate the very much higher Striatulum Zone, while the Dactyliocerates are derived from the Falcifer Zone, with perhaps something a little earlier and later. Referring to this, Buckman wrote : 'There is in any case a very big non-sequence, represented by deposits elsewhere totalling 400–500 ft., between the Ironstone and the hardened shales, which shows the danger of concluding that derived fossils must come from a bed immediately previous in date.'

INFERIOR OOLITE

(YEOVILIAN, in part—AALENIAN—BAJOCIAN, in part)

Strata of Inferior Oolite age are found *in situ* in the Kilchoan district only, where they form the bulk of the faulted outlier of Maol Buidhe, 1½ miles south-west of Kilchoan. They are irregularly exposed along a distance of about one mile on the shore on either side of Sròn Bheag Point. East of this headland the beds are less metamorphosed and best seen. Although this section is much complicated and interrupted by intrusions and faulting, the ascending sequence is observed to be from east to west. The total thickness is difficult to estimate, but probably does not exceed 120 ft. The lower half, which is fossiliferous, consists of limestones, calcareous shales, and calcareous mudstones, with shaly beds below and above. The upper portion, some 60 ft. thick, is a massive yellow or reddish sandstone in which no fossils were seen. Palæontologically, the sequence is not unlike that of the Inferior Oolite in the Isle of Raasay, where the fossiliferous layers are confined to more or less calcareous and shaly beds at the base, while the bulk of the series, presumably of *Blagdeni* and *Sauzei* date, is a yellowish sandstone with but few fossils.

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[1] G. W. Lee, 'The Mesozoic Rocks of Applecross, Raasay, and North-East Skye,' *Mem. Geol. Surv.*, 1920, pp. 32 and 67.

In the lower, mainly calcareous subdivision of the Ardnamurchan Inferior Oolite the following palæontological zones have been identified :—

- BAJOCIAN :
  - Discites
- AALENIAN :
  - Concava
  - Bradfordensis
  - Murchisonæ
  - ? Ancolioceras
  - Scissum
  - Aalensis
- YEOVILIAN :
  - Moorei.

As regards thickness, the development of the Ardnamurchan Inferior Oolite is intermediate between that of Mull, which is thin —under 100 ft.—and that of Raasay, some 700 ft. thick.

The clear section afforded by the east coast of the Isle of Raasay proves the presence of a considerable non-sequence between the Upper Lias ironstone and the Aalenian shales which rest directly on top of it. The extent of such a non-sequence in Ardnamurchan, if any, cannot be estimated, because here an intrusion separates the ironstone from the lowest bed referred to the Inferior Oolite, viz. the Moorei Beds, of which the Ardnamurchan occurrence is the only one known in Scotland.

The identification of the Moorei Beds by Buckman rests on the following :—

Catulloceras ?
cf. Dumortieria brancoi *S. Buck.*
? ,, exacta *S. Buck.*
? ,, *cf.* subexcentrica *S. Buck.*
Belemnites ellipticus *Miller.*

These were obtained by Mr. Manson from the lower portion, containing occasional cementstone doggers, of a bed of dark, hard, sandy flags or shales, 500 yds. E. 6° S. of Maol Buidhe Trigonometrical Station. From the top of the same bed ammonites of the Aalensis Zone were found. They are :—

Canavarina sp.
Cotteswoldia ?
cf. Pleydellia aalensis (*Zieten*)
cf. ,, fluens *S. Buck.*
Belemnites *cf.* quinquesulcatus *de Blainv.*

In the Isle of Mull strata of the Aalensis Zone were not detected. Here they are under 5 ft. thick, whilst in the Isle of Raasay they reach 63½ ft. Evidence of the presence of the Opaliniforme Zone, known in Mull and Raasay, was not got, but the succeeding Scissum Zone is well represented by typical forms, from the same locality, in sandy beds at the base of the limestone series :—

Rhynchonelloidea *cf.* subangulata (*Dav.*)
Lioceras gracile *S. Buck.*
  ,, opalinum (*Rein.*)
  ,, partitum *S. Buck.*
  ,, plicatellum *S. Buck.*
  ,, uncum *S. Buck.*
  ,, undulatum *S. Buck.*
  ,, *aff.* costosum (*Quenst.*)
  ,, *aff.* lineatum *S. Buck.*
  ,, *cf.* thomsoni *S. Buck.*

The collection contains also two examples of an ammonite which Buckman considered might be new, a form intermediate between *Canavarella* and *Lioceras.* Other Scottish Scissum Beds are known at Port nam Marbh and in the Ardnadrocket Glen, Lochdonhead, Mull, and on the path one mile south of Dùn Caan, Raasay, in which latter locality the stratum is little over 1 ft. thick, but crowded with ammonites.

The Ancolioceras Zone may possibly be present in 8 feet of limestone on the east side of a gully 416 yds. E. 21° S. of Maol Buidhe Trigonometrical Station, where a doubtful *Ancolioceras* (immature) was found, together with two forms of *Astarte*, one resembling *A. depressa* Goldf. and a species of *Pteria*.

Limestones on the shore 450 yds. E. 15° S. of the above Trigonometrical Station have yielded a rich fauna of the Murchisonae Zone. The lower one, blue and sandy, is 1 ft. 6 in. thick, and has yielded :—

Rhynchonellid
cf. Zeilleria anglica (*Oppel*)
Pecten articulatus *Schloth.*
  ,, demissus *Phill.*
  ,, *cf.* laeviradiatus *Waag.*
Unicardium sp.
cf. Hyattia pustulifera *S. Buck.*
cf. ,, wilsoni *S. Buck.*
  ,, sp.
Ludwigia gradata *S. Buck.*
  ,, murchisonae (*J. de C. Sow.*)
Strophogyria cosmia *S. Buck.*

This assemblage indicates early *Murchisonae* date, while the higher hard limestone 1 ft. thick is rich in forms of late *Murchisonae* date :—

Astarte, 2 spp.
Goniomya angulifera (*J. Sow.*)
Pecten demissus *Phill.*
  ,, laeviradiatus *Waag.*
Pleuromya jurassi *Ag.*
Tancredia ?
Unicardium gibbosum *Lyc.*

Apedogyria platychora *S. Buck.*
,, subcornuta *S. Buck.*
Brasilina baylei *S. Buck.*
,, sp. nov. ?
Crickia reflua *S. Buck.*
Ludwigia *cf.* murchisonae (*J. de C. Sow.*)
Ludwigina patula *S. Buck.*
,, umbilicata *S. Buck.*
Lugwigoid, [? *new*]
Manselia subacuta *S. Buck.*
,, *between* M. subfalcata *and* M. trichina *S. Buck*
Nautilus sp.
Belemnites ellipticus *Miller*

A hardened limestone 2 ft. thick on shore 390 yds. E. 25° S. of the Trigonometrical Station belongs to the Bradfordensis Zone. Fossils are :—

Goniomya angulifera (*J. Sow.*)
Pecten *cf.* demissus *Phill.*
Pleuromya jurassi *Ag.*
cf. Brasilia decipiens *S. Buck.*
Brasilina crinalis *S. Buck.*
,, *between* crinalis *and* tutcheri *S. Buck.*
cf. ,, baylei *S. Buck.*
cf. Ludwigella flexilis *S. Buck.*
cf. ,, impolita *S. Buck.*
Belemnites *cf.* aalensis *Voltz*
cf. ,, ellipticus *Miller*

At the same locality another hardened limestone 1 ft. 9 in. thick with platy top belongs in the main to the *Ludwigella cornu* horizon of the Concava Zone. The fossils obtained from this locality are all ammonites :—

cf. Asthenoceras nannodes *S. Buck.*
cf. Brasilia bradfordensis *S. Buck.*
cf. Brasilina tutcheri *S. Buck.*
? Lucya marginata *S. Buck.*
Ludwigella attentuata *S. Buck.*
,, *cf.* arcitenens *S. Buck.*
,, *cf.* cornu (*S. Buck.*)
,, *cf.* rugosa *S. Buck.*
,, *cf.* subrudis *S. Buck.*
cf. ,, arcuata *S. Buck.*
cf. ,, casta *S. Buck.*
cf. ,, flexilis *S. Buck.*
cf. ,, impolita *S. Buck.*
? ,, sp. nov.

This limestone also contains indications of the Discites Zone, as shown by the presence of *Platygraphoceras* cf. *carbatinum* S. Buck. and *P.* cf. *latum* S. Buck.

The *Ludwigella cornu* horizon was also detected in a hard white limestone with platy layers, 6 ft. thick, seen on the east side of the gully mentioned on p. 46. Its fauna is slightly different from the previous one :—

Pholadomya fidicula *J. Sow.*
,, heraulti *Ag.*
Unicardium ?

cf. Brasilina crinalis *S. Buck.*
Ludwigella *cf.* attenuata *S. Buck.*
,, *cf.* cornu *S. Buck.*
cf. ,, micra *S. Buck.*
cf. ,, vibrata *S. Buck.*
Ludwigella sp. [*new*]
cf. Paineia sp.
Belemnites *cf.* aalensis *Voltz*
,, spp.

At the same locality a white-weathering limestone with hard shaly layers, 4 ft. thick, is referred to the *Platygraphoceras* horizon of the Discites Zone.

Although the Discites fauna of the South of England is contained in one thin bed, Buckman considered it capable of chronological division, and adduces the evidence of the Ardnamurchan strata.[1] His *Reynesella* horizon is represented in 6 in. of baked calcareous beds and limestones 390 yds. E. 25° S. of the Trigonometrical Station, where Mr. Manson obtained :—

Homoeorhynchia sp. nov. [cf. *H. cynomorpha* S. Buck.]
Braunsina cornigera *S. Buck.*
cf. ,, aspera *S. Buck.*
? ,, elegantula *S. Buck.*
cf. Haugia curva *S. Buck.*
Lopadoceras *between* L. jurcatum *and* L. arcuatum *S. Buck.*
Reynesella juncta *S. Buck.*
cf. ,, piodes *S. Buck.* [or *sp. nov.*]
Belemnites sp.

An ammonite resembling *Depaoceras fallax* S. Buck, found in another calcareous bed at the same locality, suggests Buckman's *Depaoceras* horizon.

The highest fossiliferous beds of the Ardnamurchan Inferior Oolite Series consist of baked blue shales or flags, 15 ft. thick, weathering in parts into soft ferruginous sandstone, and seen in the shore cliffs 358 yds. E. 25° S. of the Trigonometrical Station. They fall in the *Docidoceras* horizon of Mr. Buckman's hemeral scheme, and have yielded :—

cf. Docidoceras cylindrodes *S. Buck.*
cf. ,, perfectum *S. Buck.*
cf. ,, planulatum *S. Buck.*
cf. Mollistephanus
Ammonite [*new ?*]
Belemnites *cf.* aalensis Voltz

In this account of the Ardnamurchan Inferior Oolite only the definitely localized fossils have been mentioned. The collection, however, contains additional specimens from loose blocks and ill-defined localities. These fossils add nothing new to our knowledge of the sequence, and only one deserves special mention a Hammatoceratid ammonite suggesting *Eudmetoceras*, a faunal element scantily represented in Scotland.

G.W.L.

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[1] S. S. Buckman, 'Jurassic Ammonites and Chronology,' 1925, p. 74. [Reprinted with corrections from 'Type Ammonites,' vol. v.]

On the north coast, the sequence of Mesozoic strata is interrupted by the Tertiary Vent-agglomerates. In the latter, on the coast opposite Achateny, east of Port Bàn, much sedimentary material occurs as blocks. One of these, a limestone, was found to contain abundant belemnites, large and small in size, exactly as in the Inferior Oolite limestone near Kilchoan. It seems, therefore, that Inferior Oolite strata were present on the north coast prior to the formation of the Tertiary Vent-agglomerates.

In the Ben Hiant district and south-east of Loch Mudle, the Inferior Oolite as well as the greater portion of the underlying Lias are absent owing to erosion in pre-Tertiary, probably pre-Upper Cretaceous times.

Bloody Bay Sandstone.—Prof. Judd drew attention to a red sandstone quarried in the west cliff of Bloody Bay, close to the east margin of Sheet 51. The locality is about a quarter of a mile south-east of Ardmore farm and of easy access from above, or by boat from Tobermory. Judd, speaking of the sandstone, justly remarks that 'the eroded surface of these beds is seen to be directly covered by the . . . basaltic lavas.'[1]

'The sandstone is of good quality and has been used in the wall of the path leading to Rudha nan Gall Lighthouse (Sheet 52). It is at least 50 ft. thick, current-bedded, and red in colour, with a small proportion of rounded grains. It also carries irregular concretionary bands of iron-ore. The outcrop can be traced for about 200 yds. and is terminated in both directions by what appears to be a fault running almost parallel with the cliffs and bringing basalt lavas down to sea-level.'[2]

The sandstone is comparable with the thick sandstone, locally reddish, which forms the upper part of the Inferior Oolite of Ardnamurchan (p. 45). The Ardnamurchan sandstone, if originally red, may have lost much of its colour through contact metamorphism.

E.B.B.

GREAT ESTUARINE SERIES

A small mass of black, fissile shales surrounded by Tertiary intrusions occurs in a sea-cliff on the west side of the promontory of Sròn Bheag, south-west of Kilchoan Bay. The thickness seen is 8 ft., and the dip is at a high angle eastwards. The shales are perhaps separated from Inferior Oolite beds, that outcrop both to west and east, by faulting of prior date to the enveloping intrusions. Dr. G. W. Lee obtained from these shales *Estheria* ***murchisonae*** Jones, a form characteristic of the Great Estuarine Series of the Island of Skye. Moreover, the Sròn Bheag shales are lithologically different from any Inferior Oolite or Liassic strata exposed near by along the Kilchoan coast, and it seems reasonably certain that they belong to the Great Estuarine Series. J.E.R.

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[1] J. W. Judd, 'The Secondary Rocks of Scotland. Third Paper. The Strata of the Western Coast and Islands,' *Quart. Journ. Geol. Soc.*, vol. xxxiv., 1878, p. 715.

[2] Quoted from G. V. Wilson *in* 'Summary of Progress for 1920,' *Mem Geol. Surv.*, 1921, p. 38.

CHAPTER V

REVIEW OF TERTIARY IGNEOUS ACTIVITY IN BRITAIN

After the completion of the survey of the Island of Mull and the publication of the results in 1924, there remained, except for St. Kilda, only one important centre of Scottish Tertiary igneous rocks which had not received detailed description. This centre, situated in the peninsula of Ardnamurchan, has been mapped and studied in detail, while additional information has been forthcoming from other districts where Tertiary rocks are developed, namely, Ireland, Arran, the Outer Hebrides, the Shiant Isles, and Iceland. The time seems ripe, therefore, for a brief general review of Tertiary igneous activity. In the following pages, a summary is attempted of our knowledge of this igneous action, in which stress is laid on the more important points of general interest which have arisen from time to time.

Igneous action referable to early Tertiary times manifested itself over a large part of Britain, but was most pronounced in the West of Scotland and North-east Ireland, where, fortunately, the post-Cretaceous age of the igneous rocks as a whole can be clearly demonstrated.

This activity can be divided partly in accordance with its mode of expression and partly according to time sequence into four main episodes.

1. The outpouring of basalt lavas of enormous lateral extent and great aggregate thickness.
2. The establishment of central vents and the formation of vent-agglomerates.
3. The intrusion of plutonic and hypabyssal rocks of divergent petrographical types at localized centres.
4. The intrusion of a multiplicity of directionally orientated dykes, mainly of basaltic composition.

The Plateau Lavas.—The earliest and most pronounced episode was the extrusion over a vast region of flow upon flow of basalt lava. These flows were erupted without explosive violence, had great lateral extent, and generally rest with a close approximation to horizontality upon a denuded platform of Cretaceous or older rocks. Such flows occupy the greater part of Co. Antrim in Ireland, and much of Mull, Morven, and Skye in Scotland; while farther afield they form the Faröe Islands and the older part of the volcanic platform of Iceland. The regions in Britain covered by these lavas are probably but remnants of a vast lava-field which have escaped complete destruction at the hands of denuding agencies. These lavas, visibly occupying in Britain some 2000 square miles of country, from their general approach to horizontality, great lateral extent, and scenic characters, are known as 'plateau lavas,' and find their parallel elsewhere in such great outpourings as have covered enormous areas in the Deccan of Peninsular India and the Snake River region of the United States of America.

That they were poured out over a land-surface is proved by the absence of intercalated marine detrital sediments, and by the frequent reddening of their upper surfaces, as well as by the occurrence of beds of bole due to deep subaerial weathering. That such decomposition was of a lateritic nature is proclaimed by the highly aluminous character of the boles and clays intercalated with the lavas of Antrim, Mull, and other regions.

Further, the generally non-explosive character of the eruptions is proved by the almost complete absence of angular ejectamenta or even of fine-grained tuffs and ashes. In Mull and Ardnamurchan, however, the lava episode commenced with the spreading out over the old rock platform of a thin but far-reaching layer of basaltic ash.

The post-Cretaceous age of the lavas of Antrim was established at an early date, but a more precise pronouncement by Forbes as to the age of the Hebridean lavas followed the discovery by the Duke of Argyll, in 1850, of leaf-beds and other lacustrine deposits intercalated with the basalts of Mull. Gardner in 1887 expressed the opinion that the flora of these leaf-beds proved the basalts to be of Eocene age, and Seward and Holttum in 1924 (Mull) saw no reason to dissent from Gardner's opinion.

The lavas, although of small individual thickness, must have collectively constituted a great lava pile of several thousands of feet. Cliff-sections sometimes show about a thousand feet of basalt in Mull and Skye, and two thousand feet in the Faröe Islands, while Ben More in Mull, a mountain made of slightly inclined plateau basalt lavas, rises from sea-level to a height of 3169 ft. The present areal distribution of the plateau lavas in Britain is approximately as follows :—

NORTH-EAST IRELAND	1550 square miles
SKYE	400 ,, ,,
MULL	280 ,, ,,
MORVEN	50 ,, ,,
SMALL ISLES	18 ,, ,,
ARDNAMURCHAN	6 ,, ,,

Petrologically the lavas present a remarkable consistency in type over the whole Hebridean region ; for the most part they are olivine-rich basaltic and doleritic rocks that carry a highly-coloured titaniferous augite and occasionally have interstitial analcite and natrolite (crinanites).

In 1874 Judd expressed the view that the outpourings of plateau basalt were connected with central vents of Hawaiian type, and claimed Mull, Ardnamurchan, Rum, and Skye as basal wrecks of great central volcanoes. This explanation of the origin of the plateau lavas was, however, supplanted in general favour by that subsequently advocated by Sir A. Geikie. Geikie in 1880 and 1888, after visiting the lava-fields of western America, came to the conclusion that the plateau basalts were due to the quiet welling up of lava through a great number of fissures distributed over the whole area affected, and that their feeders were to be found among the abundant dykes that traverse the igneous province. Such an explanation was certainly tempting in view of the great lateral extent of the lava-field, the general horizontality of the individual flows, and the then unproved existence of anything in the nature of a central vent that could be connected with the outpouring of basic lavas. As detailed work progressed, however, it was recognized that the Tertiary dykes were in reality not equally distributed but were more or less restricted to definite belts of country, and that a large proportion of them belonged to late manifestations of igneous activity. Further, Mr. Bailey has demonstrated the former existence of a caldera-like vent in Central Mull, which is supposed to have been responsible for the outpouring of a great pile of lavas upon the top of the plateau group. As differentiation progressed within the reservoir that supplied the Mull plateau basalts, basic magmas of different composition came into being (Porphyritic and Non-porphyritic Central Magma-Types, p. 79 *et seq.*). These expressed themselves first as flows intercalated sporadically with those of the Normal Plateau Type, and were later responsible for the great pile of lavas connected with the central vent. The Mull lavas of Central Types succeed the plateau lavas with general conformity, and in the Faröe Islands, also, a great thickness of such outpourings, characterized by porphyritic felspar, followed the eruption of the normal plateau basalts.

Although there has been a general acceptance of the fissure origin of the plateau basalts, we find, when we come to examine the evidence, very little of a positive character to support this view. In fact, there are many features of the lava-field that appear to require an alternative explanation. It is clear from the writings of Sir Archibald Geikie[1] that he did not insist on a uniformly distributed series of fissures to feed the flows, for, when speaking of the later plutonic intrusions, he says that 'these were mainly determined by the position of the larger or more closely clustered vents of the plateau-period, where points of weakness consequently existed in the terrestrial crust.' Also, of all the dykes encountered within the existing lava-field no undoubted case of a dyke feeding a lava-flow has been recorded, and this in spite of abundant cliff-sections. If we assume that the lavas emanated from dyke-fissures it is remarkable that in certain districts we find very few dykes traversing the platform of older rocks overlooked by the basal escarpment of the plateau lavas. Further, the basic dykes are clustered together into longitudinally orientated swarms that pass through, and are most abundant in the vicinity of the localized plutonic intrusions (p. 343), facts which go to prove that the loci of these centres were established prior to the main period of dyke-intrusion.

In spite of the great similarity in type which exists between the plateau lavas of the various disconnected regions, there are small but important differences in matters of succession that suggest

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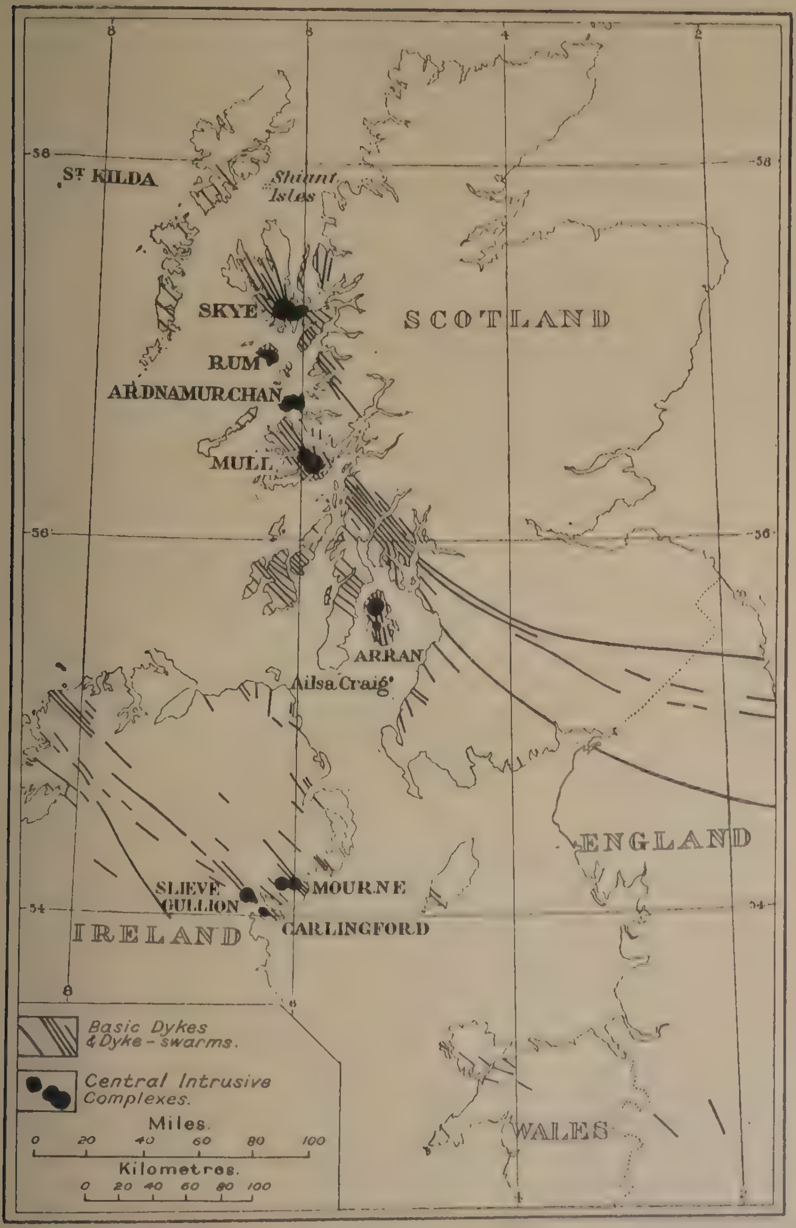
[1] Sir A. Geikie, 'The Ancient Volcanoes of Great Britain,' vol. ii., 1897, p. 464.


8
6
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56
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ST KILDA
Shiant Isles
SKYE
RUM
ARDNAMURCHAN
MULL
SCOTLAND
ARRAN
Ailsa Craig
ENGLAND
SLIEVE GULLION
MOURNE
CARLINGFORD
IRELAND
WALES
Basic Dykes & Dyke-swarms.
Central Intrusive Complexes.
Miles.
0 20 40 60 80 100
Kilometres.
0 20 40 60 80 100

Fig. 4.—*Map showing distribution of Tertiary north-west basic dykes in relation to Tertiary central intrusive complexes of the British Isles.*

Note: number of dykes is greatly reduced.

eruption from independent centres. For instance, in Antrim a series of rhyolites and a period of great erosion divide the basalts into a lower and an upper series, while in the lower series Central Types of lava (*e.g.* Giant's Causeway) are not infrequent. Central Types are also a feature of the lower part of the Plateau Group in Staffa and South-west Mull, the sequence in the latter district differing in this respect from other parts of the island. In Central Mull the normal succession of plateau basalts is broken at about 2000 ft. from the base by a thick flow of mugearitic composition, and the plateau series is succeeded by a great thickness of flows erupted from a caldera. In Canna, conglomerates and agglomerates of considerable thickness seem to occupy a low horizon in the plateau series, while at Portree in Skye, and Carsaig in Mull, volcanic agglomerates and breccias are interbedded with the plateau lavas, near their base.

Although apart from Mull there is no direct evidence of a central vent erupting basic lavas, a logical deduction is that similar conditions may have prevailed elsewhere, and thus Judd's contention that the plateau basalts originated from a series of central volcanoes of Hawaiian type cannot be dismissed as untenable. There is in fact little doubt that the Hawaiian type of centralized volcano fulfils many of the conditions demanded by the observed facts. Such vents are capable, without explosive violence and in the absence of an elevated crater, of covering thousands of square miles with thin layers of lava; and one such volcano, if comparable to Mauna Loa in extrusive power, might well account for a basaltic plateau as large or even larger than that embracing all the known Hebridean occurrences of plateau lavas. Away from the areas at present occupied by the basalts, and occasionally breaking through the lower lavas, we encounter plugs of plateau-basalt composition, and these may quite well have played a part in the formation of the basalt plateau.

Tertiary Central Complexes.—Following upon the eruption of the plateau lavas, we enter a period during which the centralization of the igneous activity becomes increasingly obvious, by the establishment of vents and the production of vent-agglomerates, and by the intrusion of hypabyssal and plutonic rocks at clearly defined centres. These centres of localized intrusion are for the most part distributed along an approximately north and south line bordering the western coast of Great Britain and east coast of Ireland (Fig. 4). Where their relations to other Tertiary rocks can be studied the intrusions invariably succeed the lavas and sometimes can be observed to follow the formation of central vents (p. 75). Those of unquestionably Tertiary age are Slieve Gullion, Carlingford, and the Mourne Mountains in Ireland, and Arran, Mull, Ardnamurchan, Rum, Skye, and St. Kilda in Scotland. The north and south alignment of these centres, other than St. Kilda, appears to be more than a matter of coincidence, and points to a definite determining line of crustal weakness, unrelated to the direction followed by the majority of the dykes that form the respective swarms. The Tertiary age of certain less important centres of intrusion may be inferred from the rock-types and structures presented by the various masses, and of these may be mentioned the Wolf Rock (phonolite), south of Land's End, Lundy Island (granite), off the north coast of Devon, and Ailsa Craig (Riebeckite-microgranite). In addition, there are minor plugs and bosses, such as those of the north of Mull, South Argyll (Sithan-t-Sluin), Antrim, and Galway, which are removed from the major plutonic centres but which take their place in the general scheme. A Tertiary age for the gabbro and granophyre of Carrock Fell in Cumberland has been suggested by Dr. Harker on account of their general similarity to Scottish Tertiary types, but precise evidence of their post-Palæozoic age is wanting.

The rock-types presented by the various centres are in many cases remarkably similar, gabbros and granophyres, which may be regarded as complementary types, being dominant. Such rocks, either alone or in conjunction, constitute the bulk of the intrusions of Slieve Gullion, Central Arran, Mull, Ardnamurchan, Rum, Skye, and St. Kilda, gabbros being more prevalent in some and granophyres in others. Granites are the chief types in the Mourne Mountains, Lundy Island, and North Arran, while in Ardnamurchan tonalitic and monzonitic masses form the latest members of the plutonic sequence. Rocks of alkaline affinities such as alkali-syenites (Mull), trachytes (Mull), riebeckite-microgranite (Ailsa Craig), and phonolite (Wolf Rock) occur as small isolated bodies of plug-like form, but seldom, except in the agglomerates of the vents, enter into the composition of the central complexes.

The manner of intrusion and the form of the plutonic bodies has been the subject of much consideration. In Skye Dr. Harker suggested that the main intrusions were of laccolithic nature, and the North Arran granite has certainly produced a dome-like elevation of the surrounding rocks. In Mull, Ardnamurchan, Central Arran, the Mourne Mountains, Carlingford and Slieve Gullion, however, the ring-dyke type of intrusion appears to be exhibited by all the more important masses, and evidence of laccolithic intrusion, except in the case of certain smaller masses, has not been observed. In Central Mull there is a remarkable series of concentric folds partly surrounding the South-east Caldera. These have been attributed to the pressure of an acid magma, intruded along the caldera margin.

Vents and Vent-agglomerates.—Frequently, as in Central Arran and Ardnamurchan, the formation of explosion-vents is the first real evidence offered of definitely centralized activity. Usually the vents are due to the uprise and explosive condition of an acid magma of alkaline affinities, which occupied the same magma reservoirs as were later responsible for the ring-dyke and other central intrusions of the respective areas.

In Central Mull such explosive activity as a recurring feature of the igneous cycle. There, the early caldera connected with the eruptions of basic lavas was followed by the intrusion of granophyre (Glas Bheinn), succeeded by the formation of extensive vents that were due to the explosive action of acid magma. Later still in the intrusive history, similar explosion-vents were again formed.

Often the vents are occupied mainly by masses of agglomerate consisting of shattered fragments of the country rock. Great masses of the vent-walls have occasionally slipped back into the vent, and thus blocks of plateau basalt, or of the Mesozoic rocks upon which the lavas rested, have been preserved, where otherwise all trace of such rocks has been removed from the neighbourhood by denudation (Arran). Other cases of the preservation of masses of plateau basalt may be instanced from Skye and Ardnamurchan.

Non-basaltic lavas are occasionally found within the areas of the vents, or, in a disrupted form, enter into the composition of the agglomerates. We may quote as examples the rhyolites of Mull and the pitchstones of Ben Hiant in Ardnamurchan. According to one interpretation the Sgùrr of Eigg pitchstone is a lava that filled a valley eroded in the plateau basalts.

Cone-sheets.—A most important class of centralized intrusion of hypabyssal type was first detected by Dr. Harker in Skye, when he discovered and mapped in the Cuillin Hills a great group of centrally inclined basic sheets. He demonstrated their circular distribution and regular inclination towards a focus situated within the great gabbro-intrusion of the Cuillins, and proved that, although younger than the gabbro, they were clearly related to the same intrusive centre. Such inclined sheets, or cone-sheets as they have been renamed in the 'Tertiary Mull Memoir,' consist of relatively thin sheets, which, viewed as members of a suite, occupy conical fissures that have a common apex and common vertical axis. Generally the sheets are moderately open-spaced, but occasionally they may be so numerous and frequent as almost to obliterate the country rock into which they have been intruded. The apex to which the sheets converge may be designated the cone-sheet focus. Their outcrops, taken collectively, may be idealized as a series of concentric circles (Fig. 5). The average inclination of the cone-sheets is as a general rule about 45°. There is, however, a definite tendency for sheets nearer to the centre to be more highly inclined than those farther away (Skye, Mull, Ardnamurchan). The central area around the axis is always devoid of cone-sheets.

Calculations from the inclination of the sheets bring out the interesting fact that in all the Tertiary centres where such sheets are developed the foci were situated at a depth of about three miles below the present surface. It also follows that such foci must have been located within or upon the surface of a reservoir capable of supplying magma to fill the fissures. This conclusion as to the depth of the cone-sheet foci is arrived at by plotting the underground continuation of the various suites of cone-sheets, assuming that the inclination of individual sheets is constant.

Cone-sheets are important features in Skye, Rum, Mull, Ardnamurchan, and Carlingford, and are clearly connected with the plutonic centres of these regions where there is evidence to show a relation between ring-dyke and cone-sheet intrusion. The idea of the development of cupolas on the main magma basin seems necessary to explain the origin of cone-sheets and ring-dykes. Such cupolas are assumed to be steep dome-like or paraboloidal upward extensions of the main magma-reservoir into relatively cool regions of the crust. From the nature of cone-sheets it is practically certain that their formation is due to an excess of magmatic pressure acting vertically upwards upon a relatively thin crustal covering, in a successful attempt on the part of the magma to raise its roof. Such was the suggested explanation of the formation of cone-sheets put forward by E. M. Anderson in 1924 (Mull), and all later work has tended towards its confirmation.

The uplift of the roof, with attendant doming of the central area above the magma-reservoir, must in every case of abundant cone-sheet injection have been of the order of thousands of feet, and an uplift of 4000 feet is regarded as the probable rise attributable to the cone-sheet intrusions of Centre 2 in Ardnamurchan (p. 178). As it appears that cone-sheet injection is dependent upon locally applied magmatic pressure there is no reason why such should not occur, or recur, whenever the magmatic pressure within the reservoir was sufficient to overcome the downward pressure of the crust. Such excessive magmatic pressure, accompanied by the intrusion of cone-sheets, was developed at more than one period and at more than one centre both in Mull and Ardnamurchan.

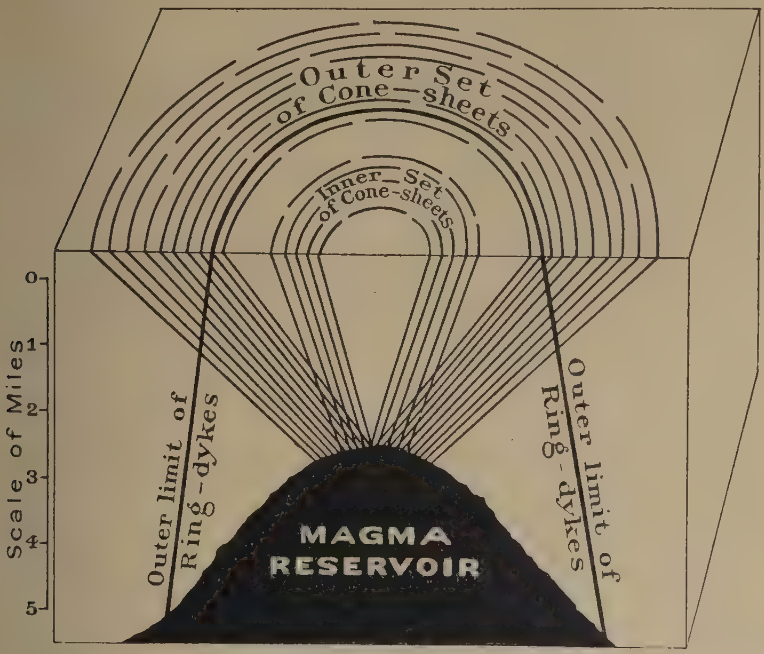

FIG. 5.—*Stereogram representing diagrammatically the Cone-sheet Complexes of Centre 2, Ardnamurchan, with reference to their inferred magma-reservoir.*

The magma that filled any particular suite of cone-sheet fissures was remarkably constant in composition, and this proves beyond doubt that all the fissures of any one set of cone-sheets were filled from a common source. Different suites, however, and cone-sheets related to different centres, usually show some magmatic variation. For instance, the early cone-sheets of Mull, belonging to the South-east Centre of the island, are mostly olivine-dolerite, while the later cone-sheets of Mull (North-west Centre), as well as the Ardnamurchan and Carlingford suites, are chiefly of quartz-dolerite composition.

Even in a suite related to one centre there is evidence of some progressive magmatic change. For example, the earlier sheets connected with Centre 2 in Ardnamurchan consist of an outer and presumably older group of quartz-dolerites of the Normal Magma-Series, and an inner group for which a magma of Porphyritic Central Type was responsible.

Ring-dykes.—The conception of ring-dyke intrusion was the result of work carried out by Messrs. Clough, Maufe, and Bailey on the cauldron subsidence of Glencoe. They found that outside a circular fault, which bounded an area of subsidence, plutonic rocks had been intruded in annular form, and to these intrusions the name ring-dyke was eventually applied on account of their vertical or almost vertical junctions. This circular fracturing and subsequent uprising of plutonic masses as annular intrusions was not recognized to be of wide application until the detailed mapping of Mull was taken in hand. Here ring-fractures and annular intrusions were found to be the dominant features. It is now realized that some, at any rate, of the plutonic masses of the Red Hills of Skye are of this nature, while in Ardnamurchan and Slieve Gullion typical ring-dykes are developed.

The general theory of subsidence, as originally enunciated for Glencoe, appears to be the only one that explains the observed facts, and therefore it is assumed that most of the plutonic rocks of the British Tertiary Centres have risen into their respective positions as the result of the subsidence into a magma-reservoir of a steep-sided conical crustal block (Fig. 5). Such subsidence would cause the welling up of magma into the fissure that bounds the subsiding mass, and, if the ring-fracture reached the surface, a central type of lava eruption would be likely to ensue, as in the case of the South-east Caldera of Mull. If, however, the subsiding block was detached from the under part of the solid crust, the fractures would not of necessity reach the surface and then the space formed over the subsiding mass would be filled with magma that would be continuous with the lateral steep-sided ring-dyke intrusion, but be more or less horizontal in disposition. Such conditions were claimed for certain granites of the Glen Coe district and appear to have been fulfilled in the Red Hills of Skye and the Mourne Mountains, and also in Ardnamurchan and Mull, where cappings of rock older than the intrusions upon which they rest suggest more or less horizontal extensions from ring-dykes beneath a roof of country rock.

Repeated subsidence at the same centre has often allowed further influxes of magma to fill reopened fissures, or to be injected up fresh circular fractures, with the result that we are presented with a succession of arcuate intrusions arranged about a common centre and vertical axis. As a general rule, in cases of repeated intrusion the older masses occur towards the outside of the complex and the younger occupy more central positions, as is exemplified by the ring-dykes of Centre 3 in Ardnamurchan and by the granites of the Mourne Mountains.

It would appear, in contradistinction to cone-sheets (p. 57), that the formation of ring-dyke fissures and the concurrent intrusion of magma are independent of excessive magmatic pressure but are consequent on crustal collapse.

It is interesting to note that the areal dimensions of the ring-dyke complexes lie between somewhat narrow limits, the average diameter being in the neighbourhood of five miles. In the appended table are given measurements of the various complexes made along maximum and minimum diameters :—

	Direction of Measurement.	Diameter in Miles.
Ardnamurchan, Centre 1	N.—S.	4¼
,, Centre 2	N.W.—S.E.	4¼
,, Centre 3	N.W.—S.E.	3¾
,, ,,	N.E.—S.W.	4¼
Mull, Centre 1	N.E.—S.W.	6 approx.
,, Centre 2	N.W.—S.E.	5
,, ,,	N.E.—S.W.	5¾
Arran, Central Ring Complex	N.W.—S.E.	2¾
,, ,, ,, ,,	N.E.—S.W.	3½
Slieve Gullion	N.W.—S.E.	7
,, ,,	N.E.—S.W.	7
Carlingford	N.W.—S.E.	5¼
,,	N.E.—S.W.	4¼
Eastern Mourne Mountains	N.W.—S.E.	6
,, ,, ,,	N.E.—S.W.	7½

It will be seen from the above table that the several ring-dyke complexes are seldom truly circular in form but exhibit eccentricity in varying degree, with one axis definitely longer than that drawn at right angles to it. It is noteworthy that when, as is often the case, the centre of ring-dyke intrusion moves to a new site, the movement takes place in the direction of the long axis of the earlier complex. Such is particularly noticeable in South-east Mull where the centre of intrusion moved to the region outlined by the Loch Bà ring-dyke, a distance of 2½ miles. In the case of Ardnamurchan, the eccentricity of the later ring-dyke complex is accentuated along an east-north-east axis, and the displacement of focus from Centre 2 to Centre 3 has taken place in this direction. The eccentricity of a ring-dyke complex and the direction of shift of the intrusive centre are probably both dependent upon the underlying magma-reservoir having a slightly asymmetric form.

Screens and Cappings.—The term screen was first applied by Mr. Wright while working in Mull to denote a narrow partition of older rock separating two steeply bounded intrusions. In Mull many arcuate screens are recognizable, intervening between ring-dykes.

Both in Mull and Ardnamurchan they are frequently of composite nature and may consist of agglomerates, lavas, and portions of older ring-dykes, and may be cut by cone-sheets that are earlier than the bounding ring-dykes. For example, the somewhat massive screen of Meall nan Con in Ardnamurchan is composed of basalt lava, agglomerate, and gabbro (p. 312). Having been contact-altered on both their inner and outer sides by intrusive rocks, screens usually show high-grade thermal alteration.

It has been pointed out that ring-dykes when in juxtaposition frequently exhibit merging junctions, and their relative age or even their separate existence may be a matter of doubt. The separation by a screen, however, along a portion of their outcrop may serve to demonstrate their individuality. In fact the importance of screens in unravelling the history of a complex cannot be stressed too greatly.

Cappings are also remnants of country rock, forming part of the roof of an intrusion, which have escaped complete denudation. Like the screens, they may be composed of any rock older than that with which they are in contact, such as pre-Tertiary sediment, basalt lava, agglomerate, or any older member of the plutonic complex.

Dykes and Dyke-Swarms.—There is no suite of Tertiary dykes of definitely pre-plateau lava age, unless it be the camptonite dykes that in certain districts cut the older rocks beyond the basalt plateau in considerable numbers. The Tertiary age of these dykes is, however, open to grave doubt, for no typical camptonite has been found to cut either the Mesozoic sediments or the Tertiary lavas.

The dykes of which the Tertiary age is certain, and which cut the lava plateau, generally have a N.W.–S.E. direction, and are closely clustered together in broad, far extending, belts that pass through the major plutonic centres. Such belts of clustered dykes are known as dyke-swarms and may be seen to traverse the centres of Skye, Mull, Arran, and North Ireland (Fig. 4, p. 53). Similar linearly directed dyke-swarms passing through plutonic centres have also been described in connexion with the Lower Old Red Sandstone granites of Loch Etive and Ben Nevis. The Tertiary dykes are mainly of basaltic or tholeiitic composition and are due to tensional stresses acting across a steeply inclined or vertical plane of considerable extent, which passes through some already determined centre. Similarly orientated acid dykes are occasionally encountered, but it has been found that these are more usually restricted to the neighbourhood of the plutonic centres and do not stretch so far afield as their basic companions. Detailed mapping has demonstrated that the period of dyke-intrusion as represented by these dykes of basic composition was of great duration and that intrusion was continued, probably spasmodically, throughout the whole period of localized igneous activity. The majority of the basic dykes, however, belong to the latter end of the period.

The dykes of the Skye Swarm stretch from the Outer Hebrides through the plutonic centre of Skye to about the same distance towards the south-east, but no member of the swarm has been proved to pass south-eastward of the Great Glen Fault. The Mull Swarm also makes itself evident as far out as the Outer Hebrides, and of all the swarms has the greatest linear extension. It passes across Loch Fyne and the Firth of Clyde, and in a less dense form can be traced through the southern uplands of Scotland into England, where, swinging into a more nearly east and west direction, it is represented by the Cleveland, Tynemouth, Acklington, and other well-known dykes.

The Arran Swarm passes outwards through Kintyre, Islay, and Jura, as far as Colonsay, and to the south-east reaches the mainland of Ayrshire and Kirkcudbrightshire.

An extensive Irish Swarm stretches across the north of Ireland north-west from Carlingford and Slieve Gullion, and in the other direction is apparently represented by numerous dykes in Anglesey and Carnarvonshire, while other members occur in Snowdonia. Its furthest extension is probably found in the post-Triassic dykes of Butterton and Swinnerton, and of Acton Reynold in the English Midlands. It is interesting to note that a dyke-swarm with a N.W.–S.E. trend passes through the plutonic centre of Lundy Island. The island is formed of a mass of granite which presents remarkable similarity to that of the Mourne Mountains, but of which the Tertiary age is still unproved.

In addition to passing through the various plutonic centres the density of the dyke-swarms is greater in their neighbourhood. Increases in density, however, are met with in the case of the Arran and Irish Swarms far to the north-west of the plutonic centres concerned. The increase in the case of the Arran Swarm is found in Islay and South Jura; in the Irish Swarm it occurs on the west coast of Donegal. The reason for this is not apparent, but it may be connected with the presence of other centres hidden beneath the sea. Calculations of the crustal stretch from the number of the dykes forming a swarm in the proximity of a centre show that the amount in the case of the Mull Swarm is one mile in twenty-four, while in the case of the Arran Swarm the figure is as large as one in eight or ten.

Radial Dykes.—In the neighbourhood of practically every plutonic centre a certain number of dykes depart from the normal direction of the dyke-swarms, and in the Cuillin Hills of Skye and in Rum arrange themselves as a subsidiary radial system (Fig. 4). Although of general magmatic similarity to the dykes of the respective north-west swarms their origin is probably connected with a different set of tensional forces.

The formation of a radial system of dykes is evidently connected with the doming of the roof of a magma-reservoir, and thus radial dykes and cone-sheets may be regarded in a measure as related though independent phenomena. The factor that determines whether the uplift of the roof should be effected by the intrusion of a multiplicity of cone-sheets or whether by simple doming with a formation of radial fissures is probably the form and depth of the magma-reservoir. For the formation of cone-sheets it appears that the upward force must be applied to a restricted area, as would be the case if the magma-cupola had steep sides and a much greater vertical than lateral extent. Doming without the intrusion of cone-sheets, and with the probable formation of radial dykes, would be effected in the case of a magma-reservoir having a gently arched roof of much greater lateral extent and, in all probability, situated at a greater intercrustal depth.

In the case of the dykes that have a north and south direction, and which are met with on the northern sides of the plutonic districts of Skye, Ardnamurchan, Mull, and Arran, it must be remembered that this direction is that of the line joining the major Tertiary plutonic centres (p. 54). They, in part, therefore, may be determined by conditions similar to those which were responsible for the north and south linear disposition of the main intrusive masses.

Sills.—Under the heading of sills are grouped those minor intrusions usually of low inclination and great lateral extent which conform to the bedding or some other plane of structural weakness of the rocks in which they occur. Owing to the generally accepted greater fluidity of a basic magma it is not surprising to find that the most typical examples are of basic composition. Where an acid magma has intruded under sill-conditions there is often a tendency for the intrusion to be restricted in lateral extent and for it to assume a laccolithic habit.

Sills are well represented among the Tertiary minor intrusions, generally grouping themselves in well-defined areas adjacent to the plutonic complexes. Excellent examples are furnished by the great group of sills of Loch Scridain in Mull and the sills of Southern Arran. The Loch Scridain sills are mainly intermediate in composition, are frequently xenolithic, and appear to have been intruded from a relatively shallow magma-reservoir subsidiary to the main reservoir of Central Mull. They furnish a most varied and interesting series of rock-types such as leidleites, inninmorites and craignurites.

A well-marked series of sill-intrusions is also developed to the north of the plutonic centre of Skye, in the Mesozoic rocks along the eastern sea-board. Dr. Harker believes that a great group of basic sills also extends generally throughout the plateau region of Skye, the Small Isles, and Mull, but this late group of basic sills has been questioned by other workers, especially in Mull. Certain sills of great thickness occur far removed from any recognized plutonic centre. They are generally of basic composition and good examples are furnished by sills in the Jurassic rocks of the Shiant Isles (p. 64), and by the Fair Head Sill in Antrim.

Composite and Multiple Dykes and Sills.—Composite intrusions of these types have the peculiarity of exhibiting a marked but orderly variation in the composition of the magma that filled the fissure. Usually such intrusions have basic exteriors with a more acid centre. The basic magma has invariably been chilled against the country rock; but the central portion of the intrusion, while exhibiting a marked difference in composition, as a rule does not chill against its more basic associate, but merges rapidly into it. It thus appears that, generally, the fissure was first filled by a basic magma that partially solidified, and that this was followed immediately by a magma of different composition, the latter naturally occupying the centre of the sill or dyke. The more acid magma presumably replaced all the basic magma that had not previously solidified and resorbed as much of the solid as its superfluous heat would allow. Such intrusions are common throughout the Tertiary Province and good examples may be cited from Skye, Mull, Arran, and elsewhere. They vary in different cases from a few feet to as much as 200 ft. in thickness. The origin of composite sills and dykes has always been a difficult problem, a final solution of which has not yet been found. Judging by the form and relations of the rocks involved, however, there appears to be no reasonable doubt of the simultaneous availability of two compositionally different magmas and of their coexistence in the same magma-reservoir, one magma following upon the other along the same fissure after a very short interval of time, before the first had an opportunity to solidify completely. There is reason to believe that in some cases the later intrusion of acid magma was aided or accompanied by a widening of the fissure.

Dr. Harker, on the evidence of the composite intrusions of Skye, considered it proved beyond doubt that the magmas responsible coexisted in subterranean reservoirs, and that the lighter acid magma overlay the denser basic one. Further, he suggested that the two magmas involved were complementary and that their production had been effected by differentiation in one and the same local reservoir. In this connexion the authors of the Mull Memoir (p. 33) agreed with Dr. Harker in assuming the coexistence of two complementary magmas produced by differentiation in the same reservoir. They further accounted for the order of intrusion by suggesting that the hotter and more mobile basic magma found access to a cold fissure more easy than would be the case for a cooler and more viscous acid magma. But, that when once the basic magma had occupied the fissure and warmed it up, the acid magma found it possible to proceed along the path that had been prepared for it.

The evidence afforded by composite intrusions that magmas of different composition can coexist in the same magma-reservoir has a considerable bearing upon other petrogenetic problems, for all the phenomena connected with ring-dyke intrusion and the observed sequence of rock-types are more readily explained on this assumption.

Multiple intrusions are usually sills or dykes that consist of several members in parallel arrangement, each member being chilled either against the country rock or against one or other of its associates. There is no difficulty in accounting for their formation, for they clearly occupy a repeatedly opened fissure that has been the passage for magma at several successive periods but not of necessity supplied from the magma-reservoir. Each influx of magma was followed by complete solidification. Another important distinction between multiple and composite intrusions is that in the former there need be no symmetrical arrangement of their component members, and that the magmas involved are not necessarily complementary. Many examples could be mentioned from the Tertiary Province, but as might be expected from their manner of formation they are sporadic and not definitely connected with any one period of intrusion or intrusive centre.

Differentiation in situ.—Another type of variation in composition is found in certain gabbro-granophyre ring-dykes of Mull and in the great picrite-dolerite sill of the Shiant Isles described by Dr. Walker. In these there is a progressive increase in basicity from the top to the base of the intrusion and a definite density stratification. Such conditions are clearly brought about by differentiation by crystallization taking place in the body of the intrusion, and the gravitative separation of early-formed basic minerals such as olivine, iron-ores, basic plagioclase and augite.

Some sills occasionally exhibit one or more bands of acid or alkaline material arranged parallel to the surfaces of the sheet, and representing the ultimate liquid residuum. It is presumed that such bands occupy regions of tension caused by contraction of the main mass during its solidification. Examples may be cited from the Permian intrusions of South-west Scotland, and also from the Tertiary picrite-dolerite sill of the Shiant Isles. H.H.T.

CHAPTER VI

TERTIARY IGNEOUS ROCKS, ARDNAMURCHAN, HISTORY OF RESEARCH

The Ardnamurchan peninsula did not offer to early workers so attractive a field for geological investigation as the other Tertiary districts of Western Scotland, and its contributions to the progress of discovery among the Tertiary igneous rocks are of much less importance than those gained, for example, in the Island of Mull. Reference may be directed to the history of research given in the Mull Memoir [1] for an account of many of the advances made in our knowledge of the Scottish Tertiaries. Only such observations as concern Ardnamurchan in particular will be mentioned here.

The researches of Jameson and Macculloch in the early part of last century were devoted almost entirely to the island districts. Ardnamurchan was known to be an area of igneous rocks, but the only record of note is a drawing by Macculloch in which he illustrates cliffs of limestone (Inferior Oolite) traversed by a complexity of 'trap veins' (1819,[2] Pl. 33, Fig. 1, facing p. 55). They are without doubt the sea-cliffs west of Sròn Bheag on the south-west side of the peninsula which are so conspicuous a feature of this rock-bound coast (*see* p. 180). Ami Boué in his *Essai*, published probably in 1820, has also figured veining of limestone by basalt. His drawing shows basalt resting upon Gryphea-limestone and sending 'veins' into it, while both limestone and basalt are traversed by later basalt 'veins' (1820, Pl. 6, Fig. 8). The locality is probably near Mingary Castle (*see* Fig. 25, p. 177).

Some fifty years later the next important contribution to Ardnamurchan igneous geology was made by Prof. Judd, when he formulated his conclusion that Mull, Ardnamurchan, Rum, and Skye are the basal wrecks of great central volcanoes. In Ardnamurchan he made some notable discoveries. He supplemented Macculloch's observation by recognizing that the great gabbro forming the nose of the peninsula was intrusive in the Mesozoic strata, which were inclined at high angles along the gabbro-margin (1874, p. 251). The volcanic agglomerates of Ben Hiant he also investigated, though wrongly concluded that they were superficial and not accumulated in vents (1890, p. 373). In his detailed petrographic work, dealing with the gabbros of Ardnamurchan and of other Tertiary districts, he made valuable advances (1886). On the other hand, his failure correctly to appreciate the field relations of the finer-textured basic rocks led him to misinterpret certain basic intrusions as lavas, such as the sill on which Mingary Castle is built, and the central intrusive dolerite of Ben Hiant (1874, pp. 261–264, and 1890, pp. 373–376).

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[1] E. B. Bailey *in* 'The Tertiary and Post-Tertiary Geology of Mull . . .' *Mem. Geol. Surv.*, 1924, pp. 40–50.

[2] Titles of works referred to by date in this Chapter are given in Bibliography, Appendix III, p. 380.

Sir Archibald Geikie, on the contrary, realized that the Ben Hiant dolerite was intrusive (1888, pp. 118–119), and that the agglomerates were contained in vents (1888, pp. 105–107). His field observations were later restated more fully in his book, 'The Ancient Volcanoes of Great Britain' (1897), together with petrographical descriptions of the Ben Hiant dolerite supplied by Dr. Harker. Geikie's observations and conclusions regarding the Ben Hiant rocks mark a great advance in this area, though now emended in certain respects (*see* pp. 121 and 162–3).

In 1900 Prof. K. Busz described a granophyre dyke from near Kilchoan (exact locality not stated) which had reacted with the gabbro into which it was intruded, and produced interesting hybrids (1901).

Prior to the detailed mapping by the Geological Survey, Dr. A. Harker visited the district. In his published writings he has made brief reference to the association of an acid intrusion (the Tonalite p. 336) with the Ardnamurchan gabbro (1904, p. 170), and to the occurrence of inclined sheets (cone-sheets) (1917, p. xciv).

Survey mapping was begun in the autumn of 1920 and was continued during the three succeeding summers. The progress of the work is recorded in the annual reports for the years 1920–1923 and 1925, and the chief advances made are stated below. Reference is directed to Pl. II (p. 71) for an explanation of many of the rock-groups mentioned in this account. The plate illustrates the grouping of the various intrusions about three successive centres, 1, 2, and 3. The recognition of these centres was not completed until 1923.

In a preliminary reconnaissance by Mr. Richey in 1920, Dr. Harker's observation of the occurrence of cone-sheets was confirmed. It was found that they formed an extensive group around the visible margins of the great gabbro mass, and were of earlier date than the latter. It was noted that these sheets (the Outer Set) inclined towards what is now called Centre 2 on Pl. II.

In 1921 progress was chiefly made in the investigation of the vents and of the gabbro mass. Several contacts between the agglomerates of Ben Hiant and vent-walls composed of the plateau basalt lavas were determined by Mr. Richey, and detailed mapping showed that on Ben Hiant there were no more than perhaps two large contiguous vents. The agglomerates were found to be interstratified with beds of tuff and sheets of pitchstone, and the latter were interpreted as lava-flows within an extensive crater. Farther north the mapping of a wide area of agglomerates (forming the Northern Vents), traversed by a group of more massive cone-sheets than those immediately around the great gabbro mass, was begun by Mr. Bailey. These sheets, as was realized later, would seem to belong to Centre 1.

The gabbro was found by Mr. Richey to be an intrusive complex of various types, and the disposition of curving outcrops of gabbro and dolerite intrusions around a more acid mass (Tonalite and

Quartz-monzonite at Centre 3) first suggested the presence of ring-dykes in Ardnamurchan.

In 1922, the gabbro-complex was mapped out in detail, and the existence of two centres of ring-intrusion was established. The occurrence of a ring-dyke complex around Centre 3 was confirmed, and it was shown that an earlier suite of ring-dykes was developed around Centre 2, around which the Outer Set of Cone-sheets had previously been recognized. It was also proved that the Outer Cone-sheets of Centre 2 are of earlier date than the outermost and perhaps earliest of the associated ring-dykes (the Hypersthene-gabbro). Further, a later Inner Set of Cone-sheets was identified cutting certain of the ring-dykes of Centre 2, but cut off by the outermost and earliest of the ring-dykes of Centre 3. Among other points of interest, an elongate volcanic vent east of Kilchoan Bay (Glas Eilean Vent) was found to be later than the Outer Cone-sheets of Centre 2, and thus of later date than the Ben Hiant and Northern Vents. Also, Prof. Judd's observation of tilted Mesozoic strata at the margin of the gabbro-complex was extended, and it was recognized that these rocks had been domed up around Centre 2 previous to the intrusion of the ring-dykes.

In 1923, advances were chiefly made in establishing a time sequence in the two ring-dyke complexes, in which work assistance was given to Mr. Richey by Dr. Thomas and Mr. Bailey. The shape of the great Ben Hiant Intrusion was finally determined, and prolongations from it simulating cone-sheets, which Geikie had previously noted, were investigated by Mr. Bailey. The mapping of several other major intrusions, cut by the Outer Cone-sheets and evidently of early date, was concluded in the area outside the gabbro-complex, around its eastern side.

When the six-inch field-maps were reduced in the office to the one-inch scale, it was realized that the Ben Hiant and Northern Vents, together with the associated major intrusions and the easterly series of massive cone-sheets (mapped by Messrs. Bailey, Richey, and Simpson), must belong to an early complex, to be referred to a centre (1) in the eastern part of the Ardnamurchan igneous district. The early date of this centre was determined by the fact above stated that the major intrusions concerned were profusely cut by the Outer Cone-sheets belonging to the earlier ring-dyke centre (2). Thus it became evident that there were three successive complexes, each of which had reference to a centre of its own.

In 1924, the Memoir on the 'Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban' was published. In it some brief references were made to Ardnamurchan, while detailed descriptions were given of North-west Mull, which was included in the area dealt with (1924, pp. 115–117, 156, 157, 160, 161, 357, 358).

During the course of the field-work in Ardnamurchan it was found that the rock-types were for the most part similar to those already investigated from Central Mull. The Interior Complex of ring-dykes, typified by containing biotite, supplied the chief departures from Mull types. In the 'Summary of Progress' for 1925 (pp. 125–127), Dr. Thomas emphasized the prevalence in

Ardnamurchan of rocks rich in alumina, lime, and magnesia as compared with the 'Normal Mull Magma-Series,'[1] correlating this feature with the concentration of basic plagioclase and olivine. More recently, in his Presidential Address to Section C at the British Association meeting at Leeds (1927), he dealt with many aspects of Tertiary igneous activity in Britain. In the same year, it may be mentioned, Dr. Burri of Zurich gave a critical review of post-Mesozoic differentiation-types, and compared the British Tertiary Province with other regions (Madagascar, Reunion, Mauritius, Rodriquez). J.E.R.

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[1] The terms, Plateau Magma-Type and Central Magma-Type of the Mull Magma-Series, as employed in the 'Tertiary Mull Memoir,' carried a strictly geographical significance, in that 'Plateau' and 'Central' bore reference to the distribution of two important groups of basalt lavas developed in that island. The Plateau Magma-Type is thus characteristic of the olivine-rich basalt lavas that constitute the greater part of the extensive lava-plateau of Mull. The Central Magma-Type is exemplified by younger, olivine-poor basalt lavas preserved by folding and faulting in the *central* part of the island. The terms are used in the present Memoir in order to facilitate comparisons with Mull. It should perhaps be stated explicitly that the two terms do not imply any particular modes of origin. Lavas of Central Magma-Type are not necessarily to be regarded as products of central volcanoes, nor are those of Plateau Magma-Type necessarily connected with fissure eruption or scattered vents.

CHAPTER VII

TERTIARY IGNEOUS ROCKS, ARDNAMURCHAN AND NORTH-WEST MULL, TIME SEQUENCE

THE western portion of the Ardnamurchan peninsula is formed of a complex of vents and intrusions penetrating Tertiary plateau basalt lavas, Mesozoic sediments, and Highland schists. The complex covers a smaller area and is relatively simpler than its neighbour of Central Mull, though built to an essentially similar plan. Its vent-agglomerates are chiefly made up of trachytic and acid materials, together with fragments of big-felspar basalt. Its characteristic intrusions are cone-sheets and ring-dykes.

The complex on three sides is bordered and to some extent encroached upon by the sea. Only its western portion, forming the nose of the peninsula, lies within one-inch Sheet 51, and the remainder extends eastwards for some five miles into Sheet 52. To meet these circumstances a description of the whole complex is given in the present Memoir and is illustrated by a coloured Memoir-map.

North-west Mull, which is included within Sheet 51, is almost entirely covered by the Tertiary plateau lavas. There are, however, numerous north-west dykes belonging to the Mull Swarm, and a few dolerite plugs and basic inclined sheets. The sheets die out southwards, and are probably outlying intrusions from the Ardnamurchan igneous focus. In the Memoir [1] dealing with the Island of Mull as a whole, this north-west portion has been already described. No further reference will be made to it in the present chapter, and attention will be confined to the Ardnamurchan area.

IGNEOUS COMPLEX OF ARDNAMURCHAN

Igneous activity in Ardnamurchan subsequent to the plateau basalt lavas consisted of a number of intrusive phases. These succeeded one another, in most cases, with a clearly indicated time sequence, though the detailed history of the various phases is often difficult to unravel. The district seems of especial value in that it illustrates in a comparatively simple manner many of the remarkable features of British Tertiary intrusive activity, that attains its grandest expression in Mull and Skye. In both Mull and Ardnamurchan, volcanic vents and hypabyssal and plutonic intrusions occur in arcuate outcrops that are arranged around central points, termed intrusion-centres. Three such centres are recognized in Ardnamurchan, and their close grouping and the concentration of the various intrusive masses permits a very complete time sequence to be worked out for the whole igneous cycle.

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[1] 'The Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1924. For the sake of brevity this Memoir will be termed in succeeding references 'Tertiary Mull Memoir.'

The investigation has been immeasurably assisted by the almost entire absence of glacial deposits and the consequent excellence of rock-exposure. The country is rugged and somewhat mountainous, but on the whole is one of comparatively low relief, the highest hill, Ben Hiant, being less than 2000 ft. in height. The low relief renders many features of the igneous geology difficult to elucidate, but has the merit of allowing of easy access ; and roads or tracks are available for reaching almost every part of the district.

In the following pages an introductory account of the igneous sequence will first be given. This will be followed by more detailed descriptions, and finally by certain general conclusions in the formulation of which Ardnamurchan will be considered in conjunction with Central Mull.

STATEMENT OF THE SEQUENCE

In Ardnamurchan, basalt lavas are met with as small outliers resting on the pre-Tertiary rocks or as masses contained within volcanic vents of later date. They form a portion, or a continuation, of the plateau group of Mull and Morven.

Subsequently to the lavas, intrusive complexes associated in their earlier stages with volcanic vents were formed around three successive centres (*see* Pl. II, p. 71). In the earliest complex, around Centre 1, agglomerates and other materials were accumulated within vents, and were followed by arcuate major intrusions and cone-sheets. The major intrusions are few in number, and certain of them are probably true ring-dykes. The more acid masses are characterized by containing xenoliths of schist, which are also found locally in one of the basic intrusions (Ben Hiant). The cone-sheets are abundant, and the majority are relatively massive.

In the next complex, around Centre 2, only one arcuate strip of vent-agglomerate is known (Glas Eilean Vent), which is situated towards the outer margin of the area affected by intrusion. Cone-sheets and ring-dykes are on the other hand well developed, and brecciation by explosive gases frequently accompanies the ring-dykes. Many of the ring-dykes contain abundant igneous xenoliths mainly of cognate fine-grained types. The cone-sheets are thinner than in the preceding phase, but attain a maximum development in point of numbers. The majority, constituting an Outer Set, are concluded to be earlier than all the ring-dykes that belong to Centre 2. The remainder form an Inner Set traversing many of these ring-dykes.

Lastly, Centre 3 came into existence situated midway between the two centres that preceded it, and its intrusions obliterated large portions of the earlier complexes. These intrusions consist almost entirely of ring-dykes, in connexion with which brecciation by explosive gases is rarely found, while igneous xenoliths are

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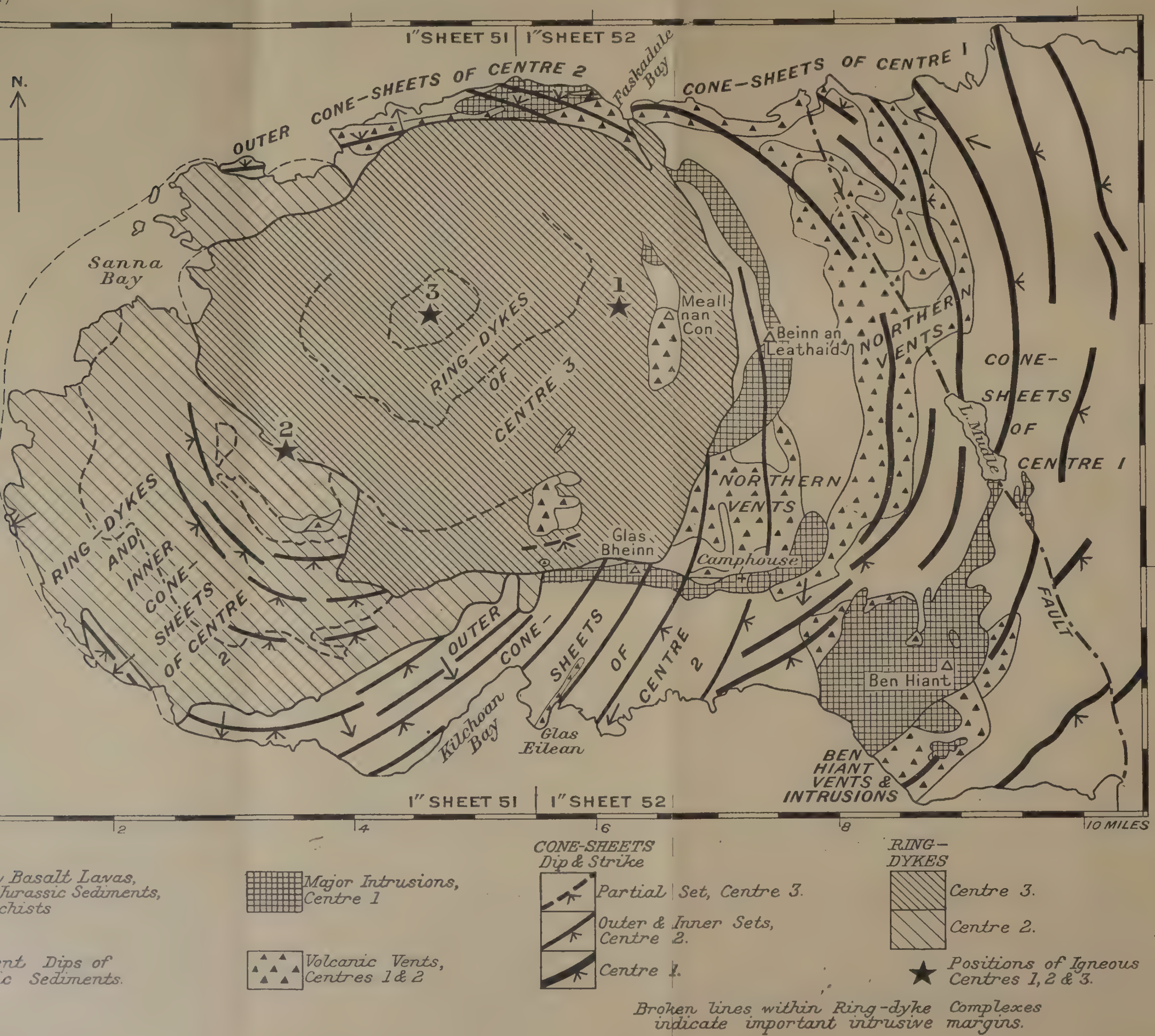
INDEX MAP OF TERTIARY INTRUSIVE COMPLEXES OF CENTRES 1, 2, AND 3, ARDNAMURCHAN.

PLATE II.



I" SHEET 51
I" SHEET 52
N.
OUTER CONE-SHEETS OF CENTRE 2
Faskadale Bay
CONE-SHEETS OF CENTRE I
Sanna Bay
3
1
2
RING-DYKES OF CENTRE 3
Meall nan Con
Beinn an Leathaid
NORTHERN VENTS
CONE-SHEETS OF CENTRE I
L. Mudle
NORTHERN VENTS
Glas Bheinn
Camphouse
FAULT
RING-DYKES AND INNER CONE-SHEETS OF CENTRE 2
OUTER CONE-SHEETS OF CENTRE 2
Kilchoan Bay
Glas Eilean
Ben Hiant
BEN HIANT VENTS & INTRUSIONS
2
4
6
8
10 MILES
Basalt Lavas, Jurassic Sediments, chists
nt Dips of c Sediments.
Major Intrusions, Centre 1
Volcanic Vents, Centres 1 & 2
CONE-SHEETS Dip & Strike
Partial Set, Centre 3.
Outer & Inner Sets, Centre 2.
Centre 1.
RING-DYKES
Centre 3.
Centre 2.
Positions of Igneous Centres 1, 2 & 3.
Broken lines within Ring-dyke Complexes indicate important intrusive margins.

only of local occurrence. Cone-sheets are also developed, but are thin and very sparse.

The successive events outlined above may be summarized as follows :—

Centre 3 (latest)	Ring-dykes, the outermost and oldest of which is cut by a few thin cone-sheets.
Centre 2	Ring-dykes, the majority of which are earlier than an Inner Set of cone-sheets, while probably all are later than an encircling Outer Set of very numerous cone-sheets. Linear vent of Glas Eilean, later than Outer Cone-sheets.
Centre 1	Set of massive cone-sheets, and the major intrusions of Ben Hiant and Beinn an Leathaid in part sheet-like. Major dyke-like and plug-like intrusions. Volcanic vents.
Plateau Basalt Lavas.	

In addition to the above, there are basic dykes mainly trending north-west, many of which may belong to the Mull Swarm (Figs. 49 and 50). Some, however, together with dykes of acid composition, are referred to an Ardnamurchan suite. As in Central Mull, the dykes, both basic and acid, are of various ages. Some, of big-felspar basalt, are of early date, being invariably cut by the Outer Cone-sheets of Centre 2. Others can be shown to be later than certain of these cone-sheets and earlier than others. Some again traverse the ring-dykes of Centre 3 and are the latest intrusions known.

The regional crustal tensions typical of the Tertiary igneous province of Britain and manifested by the north-westerly dykes must therefore have operated in Ardnamurchan during its period of localized activity. Striking evidence of late crustal stresses is supplied by very numerous crush-lines, some demonstrably tear-faults, that traverse the latest ring-dykes in no less abundance than they do the earlier complexes. The crush-lines are rarely accompanied by dyke-intrusion.

DETAILED DESCRIPTION OF THE SEQUENCE

The foregoing statement of the igneous history of Ardnamurchan is amplified in the fuller descriptions given below, in which the essentially successive character of the igneous episodes is especially stressed.

Basal Tertiary beds underlie the plateau lavas and are markedly unconformable to the Mesozoic sediments and the schists. They consist of red or greenish mudstone, often ashy in character, below which sandstone, believed to be of Tertiary age, is locally present. A mudstone has also been traced throughout Mull at the base of the lavas, and has been ascribed in the Mull Memoir[1] to the lateritic decay of a widespread basaltic ash that indicates an initial explosive phase. This is followed both in Mull and Ardnamurchan by the basalt lavas belonging to the great plateau group. Very few ash-intercalations have been found in Mull, and in Ardnamurchan none at all. The outpouring of each successive flow was frequently followed by an interval long enough for the lava-top to be covered by a layer of red earth or bole as a product of subaerial weathering. In Ardnamurchan only a few hundred feet of the plateau lavas are seen, but in Central Mull upwards of 3,000 feet are preserved. The Ardnamurchan lavas are for the most part identical in composition with the Plateau Type of Mull, being microporphyritic or non-porphyritic olivine-rich basalts. Lavas with little or no olivine allied to the Central Type of Mull are also encountered, and are sometimes porphyritic. They are interbedded with the Plateau Type, and are especially prevalent among lavas that have probably been down-faulted within the volcanic vents.

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[1] G. W. Lee *in* 'Tertiary Mull Memoir,' 1924, p. 59.

Whether an Ardnamurchan volcanic focus was in existence during the basalt lava period is indeterminable. The complexes of vents and major intrusions which occupy so large a part of the district are of altogether later date. There is also no definite evidence that the lavas originated by local fissure eruptions, for no demonstrably early dykes of similar composition to the lavas traverse the widely exposed platform of older rocks upon which the lava-outliers rest. Such early dykes as are known are chiefly composed of big-felspar basalt, a rock-type that is also met with as blocks in the vent-agglomerates.

Centre 1.—The volcanic vents of Centre 1 constitute the first evidence of the initiation of an Ardnamurchan igneous focus, for so far as known they are altogether earlier than the major intrusions and cone-sheets that are related to the same centre. Among the fragments found in the agglomerates, however, there are intrusive hypabyssal types, such as quartz-dolerite, while other evidence of pre-vent intrusion is supplied by a composite dyke that is cut off by the margin of a vent (p. 347).

The largest vent, or group of vents, included in what are termed the Northern Vents, is only in part preserved, for at either end it is bounded to the west by the Ring-dyke Complex of Centre 3, within which remnants of its materials are found as screens or cappings of agglomerate. Moreover, to the north, it is partly hidden under the sea. A considerable proportion of its agglomerate consists of brecciated country rock, mainly schist and basalt lava, but fragments of trachytic and acid volcanic rocks are also present in greater or less abundance almost everywhere. Another feature is the inclusion within the vent-complex of large areas of basalt lavas and considerable masses of Mesozoic sediments which may have slipped down bodily into their present position.

Beyond the southern limit of the Northern Vents is situated a second important vent-complex termed the Ben Hiant Vents. In contrast to the Northern Vents, the Ben Hiant complex is excellently exposed. The evidence on the south-east side of the hill shows fairly conclusively that the complex includes at least two successive volcanic orifices, each of which must have originated in stupendous explosions forming wide, open craters (Fig. 10, p. 122). The later, more southerly vent measures upwards of a mile in width, while its walls, composed partly of plateau basalts and partly of pre-Tertiary rocks, must have risen at least 1100 ft. above the original crater-floor. Within this great cavity a succession of beds of agglomerate and tuff were laid down, and at intervals pitchstone lavas were poured out which are now found as prismatically jointed sheets with amygdaloidal tops, interbedded among the fragmental accumulations. The agglomerate of both Ben Hiant Vents consists for the most part of angular pieces of trachyte, rhyolite and other acid rocks, often vesicular, which in the first instance consolidated presumably as lava in the environment of the crater, and were broken up by subsequent explosions. In addition, large blocks of big-felspar basalt with rounded or sub-rounded outlines may perhaps be bombs, though some are of enormous proportions (Pl. I, B.). Fragments of schist such as are locally abundant in the Northern Vents are never found in the Ben Hiant Vents, so that it would appear that the latter vents cleared themselves by particularly powerful or long-sustained explosions.

A plug or crater-infilling of porphyritic dolerite is now found intruded in the agglomerate of the more southerly vent, but of much more importance is a large intrusive mass of non-porphyritic quartz-dolerite, termed the Ben Hiant Intrusion (Fig. 19, p. 160). This mass links the history of the vents with the succeeding period of the cone-sheets of Centre 1. It is of exactly similar chemical composition to the basic cone-sheets, and apophyses extend from it which conform to the strike and dip of cone-sheets in their neighbourhood. It also bears a resemblance to a crater-infilling, for it rises from sea-level as a plug-like mass and then spreads out sideways at a height of 600 to 1100 feet as though occupying a volcanic orifice. Further, there is evidence that a remnant of chilled surface belonging to this upper portion has been preserved as a capping of prismatically jointed variolite that lies along the upper western slopes of Ben Hiant and very clearly grades downwards into the normal dolerite (Fig. 21, p. 167). At sea-level, a thousand feet below, where the intrusion makes contact with its wall of agglomerate, very different conditions prevailed. The edge of the dolerite is there quite unchilled, and its marginal portion is penetrated by acid veins such as characterize the margins of many ring-dykes.

Time relations between the individual major intrusions of Centre 1 cannot be fully determined, since they are rarely seen in contact with one another. Their age relatively to the massive eastern cone-sheets that conform to the same centre is also not directly determinable, except in one case on the south side of Ben Hiant, where a single cone-sheet cuts an outlying portion of the Ben Hiant Intrusion. Many of them are traversed by the Outer Cone-sheets of Centre 2, an observation that fixes a definite upper limit to their age.

Massive cone-sheets developed in the eastern part of the area have just been referred to as conforming to Centre 1, about which they are arranged concentrically. As all other evidence points to Centre 1 being of earlier date than Centre 2, it is probable that these eastern cone-sheets are of earlier date than the cone-sheets farther west, but there is very little direct evidence. Most of the cone-sheets of both areas are non-porphyritic quartz-dolerite.

Centre 2.—The first incident connected with Centre 2 appears to have been a doming up of the country rocks around it, as is indicated by the observed dips of the Mesozoic sediments (Pl. II). Subsequent to this upheaval the main period for cone-sheet intrusion ensued, during which innumerable basic injections took place (*see* Figs. 23, 24, pp. 174, 175). The cone-sheets belonging to this, the Outer Set of Centre 2, are individually much thinner than the cone-sheets referred to Centre 1. They are mainly composed of non-porphyritic quartz-dolerite, as stated above, but porphyritic varieties become prevalent towards the inner margin of the group. As is true of cone-sheets generally, individuals of this suite always present chilled contacts to older rocks, even where these older rocks are merely earlier members of the same cone-sheet complex. This latter relationship is seen again and again, and gives an impressive demonstration of the essentially successive nature of cone-sheet intrusion.

Some of the cone-sheets of the Outer Set of Centre 2 are composite, with basic marginal portions and acid centres either in sharp though unchilled contact or separated by a passage zone of intermediate composition. In such cases the interval of time between the two injections was evidently brief, and frequently insufficient to allow the basic portion to solidify completely before the acid magma was intruded. There are a few examples of a similar kind among the cone-sheets of Centre 1.

At some time subsequent to the Outer Cone-sheets the linear vent of Glas Eilean was formed, the materials of which consist largely of brecciated country rocks, including cone-sheets, veined by acid tuff. It extends parallel to the trend of the Outer Cone-sheets in its neighbourhood, and thus conforms to Centre 2 (Fig. 13, p. 132).

The relative ages of the Outer Cone-sheets and the Ring-dykes of Centre 2 are determined by the fact that the outermost and probably oldest ring-dyke (the Hypersthene-gabbro, *a* of Pl. V) is practically free from all cone-sheets, while the Outer Cone-sheets that traverse the wall-rock outside are contact altered (*see* Fig 28, p. 219).

The intrusion of the Ring-dykes of Centre 2 was interrupted by the injection of the Inner Cone-sheets, belonging to the same centre. These cone-sheets are less abundant than the Outer Set, are much more steeply inclined, and are almost all porphyritic dolerites. No example of composite habit has been noted. The ring-dykes traversed by the Inner Cone-sheets are :—the Hypersthene-gabbro (*a*),[1] a much altered gabbro (*b*), a Granophyre (*c*), Quartz-gabbros (*c′*, *c″*, *d*), and a Quartz-dolerite veined by Granophyre (*e*). The ring-dykes that are uncut by the Inner Cone-sheets are all probably of later date and include :—a Eucrite (*f*), and Quartz-gabbros (*g* and *h*). No complete time sequence can be arrived at for these various ring-dykes, but the order in which they are lettered is, so far as determinable, their order of intrusion.

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[1] The index-letters applied to individual ring-dykes in this and subsequent chapters are as given on Pl. V, p. 201, and Table VII, pp. 201, 202.

Shattering of ring-dykes is, as already mentioned, more especially a feature of Centre 2. In one case it is evidently due to earth stresses. More frequently it is to be ascribed to the action of explosive gases given off from an intruding magma, and comparable to the brecciation met with in the walls of some volcanic vents, though of an especially intense kind. Shattering by earth stresses is exemplified by the outer margin of the Quartz-gabbro (*c*), which was highly sheared, with the development of flinty crush-rock, prior to the intrusion of the Inner Cone-sheets. Such localized shearing may have been connected with fault-movements along a ring-fissure, but since the ring-dyke now in contact with this margin, the Eucrite (*f*), is of much later date, its exact significance cannot be determined. As an instance of the shattering attributable to explosion, we may cite the Quartz-dolerite (*e*). This ring-dyke was injected along the inner margin of the Hypersthene-gabbro (*a*). The arc-shaped cavity which the Quartz-dolerite now occupies appears, in part at least, to have resulted from explosions. South of Sanna Bay, for example, its wall composed of the Hypersthene-gabbro is in an absolutely comminuted state, while xenoliths of the broken-up rock are found enclosed in the intruding Quartz-dolerite. The Quartz-dolerite after consolidation was itself brecciated and profusely net-veined by a succeeding granophyre magma (Fig. 34, p. 257). Another instructive example is provided by the Eucrite (*f*), which was shattered throughout much of its length and then granulitized. The shattering extends also to the innermost part of the Quartz-gabbro (*g*) in contact with the Eucrite. The explosive gases and the heat required for the granulitization were presumably derived from some later intrusion which underlies the Eucrite below the present level of denudation.

In the case of the Central Ring Complex of Arran the interconnexion of explosive brecciation and igneous intrusion has also been advocated by Dr. G. W. Tyrrell,[1] while at Slieve Gullion in Ireland an example of alternating explosive and intrusive phases referable to a single ring-fissure, has been recorded by the writer,[2] following on the work of Nolan.[3]

Centre 3.—The ring-dykes which almost entirely constitute the complex of Centre 3 can be arranged fairly definitely in a time sequence, the older intrusions occurring at the periphery and the youngest in the interior. In the peripheral group the Quartz-gabbro (A), and probably the Fluxion Gabbro (B), are earlier than the Great Eucrite (E). This Eucrite is in turn earlier than probably all the ring-dykes of the interior.

Except for a narrow ring-dyke of eucrite (H) the Interior Complex within the Great Eucrite consists entirely of biotite-bearing ring-dykes including :—Biotite-eucrite (G) ; Quartz-dolerite veined with Granophyre (I) ; Quartz-biotite-gabbros (J, J′, J″) ; Fluxion

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[1] G. W. Tyrrell, 'The Geology of Arran,' *Mem. Geol. Surv.*, 1928, p. 168.

[2] J. E. Richey, 'Tertiary Ring-dykes of Slieve Gullion, Ireland,' *Rep. Brit. Assoc.* for 1928, 1929, p. 544.

[3] J. Nolan, 'On the Ancient Volcanic District of Slieve Gullion,' *Geol. Mag.*, 1878, p. 445.

Biotite-gabbros (K, L); Tonalite (M); and a small central boss of Quartz-monzonite (N). The Great Eucrite (E) is seen to be cut by the Quartz-dolerite (I) and by the Fluxion Biotite-gabbro (K). Another Fluxion Biotite-gabbro (L) forms a practically complete ring-outcrop around the Tonalite (M), by which it is cut. The Tonalite is also demonstrably later than the Quartz-biotite-gabbros (J′, J″). The small central boss of Quartz-monzonite is later still.

In the case of Centre 3, as in Centre 2, ring-dyke intrusion was interrupted by the injection of basic cone-sheets. These traverse the southern portion of the Quartz-gabbro (A) (Fig. 39, p. 286), and appear to be a partially developed set. Individual cone-sheets near to the Great Eucrite (E) are highly contact altered, and for this reason the set as a whole is considered to be pre-Great Eucrite in age.

The prolonged time required for the formation of the two ring-dyke complexes may be appreciated in various ways. For instance, if we consider the order of intrusion of the various magma-types, we find that there has been repeated alternation, mainly of acid and basic gabbros (p. 209). Thus differentiation repeatedly affected the contents of the underground magma-reservoir during the formation of the ring-dykes. Again, the consolidation of a large individual mass such as the Great Eucrite (E) must have taken a considerable period for its completion. Its margins are unchilled, and its coarsely-crystallized minerals suggest slow cooling under plutonic conditions. A final phase of its crystallization, when the contained fluxes became concentrated, is represented by very coarse-textured areas of gabbro-pegmatite that occur throughout the intrusion, and also by abundant gabbro-pegmatite veins. There are differences in detail in regard to the cooling conditions of the various ring-dykes. For instance, the Hypersthene-gabbro (*a*) possesses a wide outer margin of finely-crystallized rock, which gradually passes into normal coarsely-crystallized gabbro towards the interior of the mass. The fact remains that the coarse interior must have taken a very long time to consolidate.

Ring-dykes as a rule produce much more marked contact alteration where adjacent to sediments, ashes, lavas or minor intrusions than where they come against earlier members of the ring-dyke complex. This is in keeping with general experience of plutonic contacts in other districts. It is evidently difficult to produce notable change in a fresh coarsely-crystalline igneous rock by reheating under plutonic conditions. The careful examination that has been made of the various ring-dyke contacts shown in Pl. V demonstrates, however, that the time-interval between successive injections was always long enough to permit complete crystallization of the earlier of the two intrusions met with at any particular junction. Such considerations, on the basis of probabilities, lead us to the conclusion that the interval between two injections must, as a general rule, have extended considerably beyond the time taken in consolidation. An exception is provided by one of the ring-dykes of the Interior Complex of Centre 3, the Sithean Mòr Fluxion Biotite-gabbro (K), that is accompanied along part of its outer margin by a mass of quartz-biotite-gabbro (not shown separately in Pl. V). Between the two kinds of gabbro there is an interbanded junction with alternate bands composed of the fluxioned and quartz-bearing gabbros, and each variety of band becomes thicker towards the mass to which it corresponds (Fig. 47, p. 330). The most obvious explanation seems to be that the injection of the two gabbros in this particular case followed one another so closely that they became interbanded along their mutual junction.[1]

GENERAL CONCLUSIONS

The foregoing account summarizes the main features of the Ardnamurchan igneous period, and will suffice to show that this period, as in the case of every other Tertiary intrusive district of Britain, is remarkable for the number and variety of its successive episodes. Yet the details that we are able to unravel at the present level of denudation can only furnish us with a partial history of all that took place within the extreme vertical limits of the complex; for these limits may be regarded as set by the top of the parent magma-reservoir and that other remote level, the ground-surface as it existed when igneous activity came to an end.

In the case of intrusive igneous rocks, little can, as a general rule, be inferred with confidence concerning those portions which continue downwards below the present level of observation or which have been removed by erosion. The sequence of events as demonstrable at the present denudation-surface in Ardnamurchan is, however, suggestive of the growth of a volcanic pile above the area affected by intrusion. The volcanic vents of Centre 1 have presumably been formed at a relatively higher crustal level than the ring-dykes of Centres 2 and 3. They offer a striking contrast to the coarsely crystallized ring-dykes of Centre 3, which at a long subsequent date were intruded through them. We are led to assume that volcanic accumulations extended to a very considerable height above the level now exposed, in order to allow of the deep-seated crystallization usually manifested by the ring-dykes. In the case of Centre 2, however, the intense brecciation that accompanies many of its ring-dykes points to relatively superficial conditions. Further, to this centre belongs the linear vent of Glas Eilean, situated towards the outer limit of the belt of Outer Cone-sheets that encircle the ring-dykes. It would seem quite probable that such a linear vent may be guided by a ring-fissure below ground, and logically that some of the ring-dykes of Centre 2 continued upwards into arcuate vents.

Later still in the history of Ardnamurchan we find that the complex of Centre 3 is almost entirely composed of ring-dykes, and that these are rarely accompanied by brecciation. The complex as a whole would thus appear to be more deep-seated than that of Centre 2. On the other hand, it may be possible that this rarity of brecciation is due to the ring-fractures that preceded intrusion being connected by cross roof-fractures instead of continuing upwards to the ground-surface. One of the outermost of the ring-dykes of Centre 3—the Quartz-gabbro (A)—is indeed seen to extend under a roof of older rocks, and along this part of its course at least cannot have had any connexion with the surface.

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[1] For a more comprehensive introductory account of the ring-dykes, *see* Chap. XV.

Present-day research certainly tends to reaffirm the conception of Judd that in Ardnamurchan, as in other Tertiary intrusive districts of the West Highlands, what we now see exposed is the 'basal wreck' of a great volcano.[1] But the subservience of the observed intrusive phenomena to well-defined laws and their essentially successive character are the features which recent work has more especially emphasized. Arcuate fissures resulting from the relief of localized earth stresses and subsequently filled with magma would appear to indicate very precisely the existence and location of an underground magma-reservoir (*see* Fig. 5). The three successive complexes in Ardnamurchan manifest a shifting of the locus of intrusion and seem to show that successive magma-reservoirs differing but little in position were formed. There can be little doubt that the reservoirs underlying the various intrusive districts of Britain came into existence in the first instance by the underground displacement of country rock.[2] It must also be admitted that each of the successive reservoirs of Ardnamurchan remained constant as regards position for a prolonged time, during, in fact, the related periods of intrusion. The existence of such successive reservoirs for lengthy periods is perhaps the most interesting point that the Ardnamurchan district appears to us definitely to prove.

Essentially similar conclusions have been arrived at from a study of Central Mull. There it has been found that two successive centres of intrusion were established along a south-east–north-west line. Explosion-vents, cone-sheets, and ring-dykes are associated with both centres. An early Kilauean phase of vulcanicity, connected with the south-east centre, is demonstrated by a localized development of pillow lavas marking the site of an oft-renewed crater-lake. It is true that at both the Mull centres, a prevalence of screens of older rocks (basalt lavas, agglomerates, etc.), between neighbouring ring-dykes, made it impossible to work out a time sequence for many of the individual intrusions. It is, however, fully evident that in Central Mull as in Ardnamurchan each complex must have taken a prolonged period for its development.

J.E.R.

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[1] J. W. Judd, 'The Secondary Rocks of Scotland. Second Paper. On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata,' *Quart. Journ. Geol. Soc.*, vol. xxx., 1874, p. 220.

[2] *See* H. H. Thomas, *Pres. Address*, *Sect. C*, *Rep. Brit. Assoc.* for 1927 Leeds), p. 45.

CHAPTER VIII

GENERAL PETROLOGY

In the Memoir dealing with the Tertiary igneous rocks of Mull an attempt was made to give some account of the composition and variation of the Tertiary Magma at successive stages in its history. We were able to recognize, as represented by the rocks, definite compositional characteristics which further enabled us to select average compositions around which individual rocks of the Tertiary Province seemed to group themselves. These average compositions, representative of widespread rock-types and based upon a great number of trustworthy analyses, we assumed to mark certain stages in the evolutionary history of the magma, and thus might logically be regarded as indicative of definite magma-types. The recognition and establishment of such types appeared to be the natural preliminary to any discussion of the probable course of differentiation, for such types will of necessity stand in either lineal or collateral relationship to each other. Magma-types that appear to have a direct lineal relationship may collectively be regarded as constituting what may be termed a magma-series, while divergent types may constitute collateral series.

The study of the Tertiary centres of Arran,[1] the Mourne Mountains [2] and, more particularly, of Ardnamurchan has enabled us to confirm, expand and, in some instances, to modify our previous conceptions.

In Ardnamurchan the plateau basalts are feebly represented, but they are of the usual type and composition and may be considered, as in other districts, to have had a much greater extent than they now exhibit. Our main concern is with the intrusive masses that occur as ring-dykes, cone-sheets, and sills.

The major intrusions of the Ardnamurchan centres are mostly of gabbro and quartz-gabbro with quite subordinate masses of granophyre. At the latest of these centres, however, following upon the Great Eucrite Ring-dyke, in point of time, we encounter an important development of tonalitic and quartz-monzonitic types that are practically unrepresented amongst the intrusive masses of the other Tertiary centres, with the exception, perhaps, of Slieve Gullion in Ireland.

A chemical and microscopical study of the plutonic intrusions of Ardnamurchan indicates that the bulk of the quartz-gabbros belong to the Porphyritic Central Magma-Type as established in Mull, but that the tonalitic and quartz-monzonitic types, together with certain more acid plutonic masses of other Tertiary centres, suggest the existence of an independent collateral magma-series with entirely distinct end-products of differentiation.

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[1] G. W. Tyrrell, 'The Geology of Arran,' *Mem. Geol. Surv.*, 1928.

[2] J. E. Richey, 'The Structural Relations of the Mourne Granites.' *Quart Journ. Geol. Soc.*, vol. lxxxiii., 1928, p. 653.

THE NORMAL MAGMA-SERIES

The Normal Magma-Series (Fig. 6) as established in Mull and as described in the Memoir[1] on that island was based primarily on the chemical and petrographical characters of a very large suite of rocks. It appears as a typical lineal series and has a wide range of composition from basic to acid. At its basic end stands the Plateau Type, and this is followed by the Non-porphyritic Central Type, and through several intermediate and sub-acid stages reaches the Acid Magma-Type (Fig. 6).

%	PLATEAU TYPE	NON-PORPHYRITIC CENTRAL TYPE		INTERMEDIATE & SUB-ACID TYPES			ACID TYPE	%
SiO_2	45	47	50	55	60	65	70	SiO_2
Al_2O_3	15	14	13	13	13	12	12	Al_2O_3
$FeO + Fe_2O_3$	13	13	13	11	8	6	4	$FeO + Fe_2O_3$
MgO	8	6·5	5	4	3	1·7	0·3	MgO
CaO	9	10	10	7	5	3	1·5	CaO
Na_2O	2·5	2·6	2·8	3	3·3	3·5	3·3	Na_2O
K_2O	0·5	0·7	1·2	1·7	2·2	3	4	K_2O
TiO_2	2·5	2·5	2·5	1·8	1·2	1·0	0·5	TiO_2

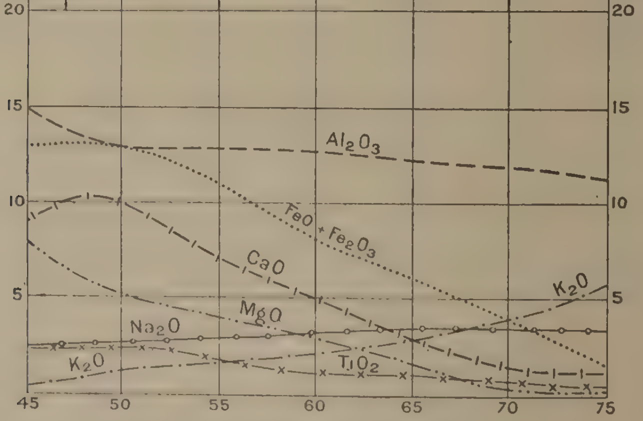

FIG. 6.—*Variation-Diagram, Normal Magma-Series.*

This magma-series is responsible for most of the igneous rocks of Mull. Many of these have an immature or hypabyssal type of crystallization. Where such is the case, it is more or less certain that each rock is a faithful expression of the magma which gave rise to it, and has not been compositionally modified to any extent during its intrusion or solidification.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 14.

In Northern Mull and Ardnamurchan most of the lavas and minor intrusions, as well as granophyres such as those of Grigadale, are representatives of this series, and we have reproduced the Mull variation diagram for comparative purposes. A recent analysis of the granite of the north of Arran (Table III, C) enables this diagram to be extended slightly in the acid direction, and analyses of rocks from other areas suggest that this magma-series may be regarded as generally applicable to the Tertiary Province.

Almost all the various magma-types embraced by the Mull Series have their representatives within the Ardnamurchan centres, although there is, perhaps, much less variety in their solid expression. In many cases rocks encountered in Ardnamurchan, such as plateau lavas, basalt and dolerite dykes, etc., proved on microscopic examination to be so similar to types represented in Mull or some other Tertiary centre that further chemical analyses were deemed unnecessary. For comparative purposes, however, analyses of important Ardnamurchan rock-types, representative of this magma-series, were undertaken, and these are given in Tables II and III, pp. 82 and 84.

The compositional characters of the magma-series as a whole are set out in Fig. 6. The main features are the fairly constant Al_2O_3 with falling Iron, CaO and MgO towards the acid end, and the concentration of TiO_2 towards the basic end where the falling CaO with rising MgO, and the high Iron and Al_2O_3, indicate the concentration of olivine, augite, and iron-ores at the expense of basic plagioclase felspar. There is a general tendency throughout a large part of the series for Na_2O to predominate over K_2O, but close to the acid end there is a rapid relative concentration of K_2O causing the two alkali curves to cross and diverge at a silica percentage of about 68. The series is one throughout which the plagioclase felspars play an important part, as is indicated by the flat curve representing a more or less constant content of Na_2O.

The Plateau Magma-Type.—The Plateau Type in the north of Mull is represented by a great development of basalt lavas and a great number of basic dykes. In the Ardnamurchan peninsula it is clearly demonstrated by a small development of plateau lavas and by a considerable number of dykes that have basaltic or doleritic types of crystallization. The lavas of Ardnamurchan, however, are possibly referable to the Mull centre (p. 107), and the dykes, which are of all periods of intrusion, belong in part to the Mull Swarm (p. 343). The great group of Early Basic Cone-sheets, an early expression of this magma-type in South-central Mull, is not met with in Ardnamurchan. As pointed out in the Tertiary Mull Memoir the essential minerals of this magma-type are olivine, augite, basic plagioclase and iron-ore, with a certain amount of interstitial matter, which in certain cases can be demonstrated to yield analcite, natrolite, and possibly nepheline on crystallization. A purple tint indicative of the presence of titanium is usually exhibited by the augite, which does not occur either as phenocrysts or small idiomorphic crystals but exhibits an ophitic structure.

The nature of the residual matter left over on the solidification of this magma-type is noteworthy in connexion with the alkaline segregations encountered by the Survey in certain of the plateau lavas of Mull and more recently by Dr. Walker in a thick Tertiary Sill of plateau basalt composition occurring in the Shiant Isles. In the lavas the segregations consist of titaniferous augite, labradorite and ilmenite with a residuum of alkali-felspar, aegirine-augite and analcite, the presence of nepheline being expected but not proved. In the Shiant sill Dr. Walker finds that the segregations are of the nature of an alkali-syenite similar to the Carsaig Syenite in Mull but with the addition of large crystals of nepheline.

TABLE II

NON-PORPHYRITIC CENTRAL MAGMA-TYPE (*see* Fig. 6).

	QUARTZ-DOLERITE.					
	I.	II.	III.	IV.	A.	
SiO_2	50·10	50·67	50·79	51·06	52·16	SiO_2
Al_2O_3	12·08	11·89	12·10	11·79	11·95	Al_2O_3
Fe_2O_3	4·35	8·61	4·10	3·41	4·86	Fe_2O_3
FeO	11·18	7·08	11·29	11·68	9·92	FeO
MgO	3·93	3·94	4·02	4·35	3·77	MgO
CaO	8·85	7·75	8·05	7·57	7·14	CaO
Na_2O	3·06	2·94	3·50	3·36	2·36	Na_2O
K_2O	0·96	1·50	1·30	1·23	1·74	K_2O
$H_2O > 105°$	1·01	0·77	0·23	0·92	1·95	$H_2O > 105°$
$H_2O < 105°$	0·53	1·05	1·56	0·56	0·56	$H_2O < 105°$
TiO_2	2·98	2·88	2·46	3·10	3·25	TiO_2
P_2O_5	0·17	0·55	0·22	0·23	0·24	P_2O_5
MnO	0·25	0·20	0·26	0·20	0·18	MnO
CO_2	trace	0·21	0·17	—	0·18	CO_2
FeS_2	0·28	0·02	0·28	—	—	FeS_2
Fe_7S_8	0·02	—	—	—	—	Fe_7S_8
SO_3	—	0·38	trace	—	—	SO_3
S	—	—	—	0·11	0·18	S
Cr_2O_3	trace	trace	0·02	—	—	Cr_2O_3
(Co, Ni)O	—	0·00	—	—	—	(Co, Ni)O
BaO	0·05	0·02	trace	0·00	—	BaO
LiO	—	0·00	trace	—	—	Li_2O
Cl	—	—	—	0·00	—	Cl
C	—	—	0·04	—	—	C
Organic matter	—	0·01	—	—	—	Organic matter
	99·80	100·47	100·39	99·57	100·44	

I. (22819; Lab. No. 788.) Quartz-dolerite, Talaidh type. Cone-sheet, Centre 2, Ardnamurchan. Quarry west of crofts at Tom a'Chrochaidh, ½ mile E. of Kilchoan. *Anal.* B. E. Dixon.

II. (21253; Lab. No. 737.) Quartz-dolerite. Ben Hiant Main Intrusion, Centre 1, Ardnamurchan. Cliffs 700 feet above shore, Camas nan Clacha Mòra, Ben Hiant. *Anal.* B. E. Dixon.

III. (23296; Lab. No. 792.) Quartz-dolerite, Talaidh type. Cone-sheet, Centre 2, Ardnamurchan. Shore at Rudha Àird an Iasgaich, $\frac{7}{8}$ mile S.E. of Kilchoan. *Anal.* B. E. Dixon.

IV. Quartz-dolerite, Talaidh type. Cone-sheet. Same intrusion and locality as preceding. *Anal.* H. S. Washington.

A. (18467; Lab. No. 444.) Quartz-dolerite, Talaidh type. Cone-sheet. 70 yds. S. of summit, Cruachan Dearg, Mull. Quoted from 'The Tertiary and Post-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1924, p. 17. *Anal.* F. R. Ennos.

The Non-porphyritic Central Magma-Type.—This type, which in Mull accounted for a thick series of lavas, many of the sills, most of the Late Basic Cone-sheets, and many dykes, in Ardnamurchan is responsible for most of the cone-sheets, the relatively large intrusion of Ben Hiant, and many dykes; but it is practically only the more acid representatives of the type that here find expression.

The essential minerals are augite, plagioclase felspar and magnetite, the rocks being either olivine-free or having olivine as a minor constituent. There is usually an acid residuum which on crystallization yields alkali-felspar and quartz. The kind of solidification or crystallization which the type affects is very variable and may be largely glassy, variolitic, basaltic or doleritic.

The analyses given in Table II are of Ardnamurchan occurrences, with examples taken from Mull for comparison. We have been able to include a hitherto unpublished analysis (IV) of an Ardnamurchan cone-sheet by Dr. H. S. Washington. It will be seen that the Ardnamurchan rocks compare closely with the Talaidh type of quartz-dolerite as established in Mull, and although somewhat richer in CaO and Al_2O_3 fall naturally into their place in the Normal Magma-Series.

Intermediate, Sub-acid, and Acid Magma-Types.—Of the remaining magma-types of the Normal Magma-Series the few representatives in Ardnamurchan are craignuritic cone-sheets and sills, the pitchstone lavas of Ben Hiant, and certain granophyres (*see* Table III, Anal. I, II, III). The pitchstone lavas are especially interesting as furnishing an effusive example of a magma that as far as Mull is concerned is only represented as an intrusive phase. Their compositional and mineralogical identity with the Inninmorite pitchstone of the Mull sills, marks them out as representing a very definite stage in the magma-series. Their essential minerals are enstatite-augite, augite, plagioclase and magnetite with a very considerable residuum of glass that on devitrification yields mainly alkali-felspar and quartz.

The Acid Magma-Type in Ardnamurchan demonstrated itself at an early stage, and as in Mull and most other Tertiary centres was responsible for the explosion phenomena connected with the vents, the shattering and injection of some of the ring-dykes of Centre 2, and certain important intrusions of augite-granophyre.

The texture of the rocks to which it has given rise varies from glassy to coarsely granophyric, while the rocks themselves are

TABLE III

SUB-ACID AND ACID MAGMA-TYPES (*see* Fig. 6)

	INNINMORITE.			GRANITE AND GRANOPHYRE.			
	A.	I.	II.	III.	B.	C.	
SiO_2	64·13	64·30	66·06	68·42	71·60	74·87	SiO_2
Al_2O_3 ..	13·15	14·18	13·14	13·54	13·60	11·24	Al_2O_3
Fe_2O_3	1·08	1·09	2·27	2·53	2·40	0·34	Fe_2O_3
FeO	6·31	4·44	2·84	2·02		1·22	FeO
MgO	1·08	1·47	0·77	0·22	0·21	0·22	MgO
CaO	3·62	2·87	2·75	2·13	2·30	1·30	CaO
Na_2O ..	3·64	4·30	4·28	5·12	5·55	3·31	Na_2O
K_2O	2·32	2·83	1·54	4·08	3·53	5·68	K_2O
$H_2O > 105°$ ..	2·71	3·02	3·38	0·15	0·70	0·49	$H_2O > 105°$
$H_2O < 105°$ ..	0·36		0·74	0·25		0·29	$H_2O < 105°$
TiO_2	1·19	0·75	1·08	0·81	—	0·26	TiO_2
P_2O_5	0·31	0·17	0·09	0·38	—	0·09	P_2O_5
MnO	0·27	0·26	0·31	0·10	—	0·05	MnO
CO_2	—	0·00	0·37	0·06	—	0·49	CO_2
FeS_2	0·00	—	trace	0·05	—	0·33	FeS_2
SO_3	—	0·00	0·16	trace	—	—	SO_3
Cr_2O_3	—	0·00	trace	trace	—	0·02	Cr_2O_3
(Co, Ni)O ..	0·00	—	0·00	—	—	—	(Co, Ni)O
BaO	0·09	0·16	trace	0·03	—	0·04	BaO
Li_2O	0·00	—	trace	trace	—	0·00	Li_2O
F	—	—	—	—	—	0·00	F
C	—	traces	—	—	—	—	C
Organic matter ..	—	—	0·02	—	—	—	Organic matter
	100·26	99·84	99·80	99·89	99·89	100·24	

A. (15990; Lab. No. 387.) Fairly glassy Inninmorite or Inninmorite-Pitchstone. Sheet. $\frac{3}{16}$ mile S.W. of Trigonometrical Station on Beinn an Lochain, Mull. Quoted from E. M. Anderson and E. G. Radley, *Quart. Journ. Geol. Soc.*, vol. lxxi., 1915, p. 212. *Anal.* E. G. Radley.

I. Inninmorite-Pitchstone. Lava. E. slope of Ben Hiant, Ardnamurchan. *Anal.* Harcourt Phillips.[1]

II. (21255; Lab. No. 739.) Inninmorite-Pitchstone. Lava. In stream bank $\frac{5}{8}$ mile S. 12° E. of Trigonometrical Station at 1729 ft., Ben Hiant, and $\frac{1}{2}$ mile W. 3° S. of Bourblaige, Ardnamurchan. *Anal.* B.E. Dixon.

III. (22820; Lab. No. 789.) Augite-granophyre. Major intrusion, Centre 2, Ardnamurchan. 800 yds. S. 30° E. of Grigadale. *Anal.* B. E. Dixon.

B. Augite-granophyre. 100 yds. E. of summit, Carrock Fell, Cumberland. Quoted from A. Harker, *Quart. Journ. Geol. Soc.*, vol. li., 1895, p. 129. *Anal.* G. Barrow.

C. (24380; Lab. No. 820.) Biotite-granite. Northern granite mass, Arran. Glen Rosa, $\frac{1}{2}$ mile above confluence with Garbh Allt. Quoted from G. W. Tyrrell, 'The Geology of Arran,' *Mem. Geol. Surv.*, 1928, pp. 155–156. *Anal.* B. E. Dixon.

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[1] Supplied by Dr. A. Harker.

rhyolites, dacites, felsites, and coarse and fine granophyres, in which the dominant minerals are alkali-felspar and quartz. Augite is the most usual ferromagnesian constituent. Hornblende and biotite are exceptions and where present are demonstrably products of interaction between the acid magma and basic xenolithic or xenocrystal matter.

It is interesting to note that the Grigadale granophyre compares somewhat closely as regards composition with the Carrock Fell granophyre of presumed Tertiary age.

TABLE IV

PORPHYRITIC CENTRAL MAGMA-TYPE (*see* Fig. 7)

	EUCRITE, GABBRO, AND BASALT.								
	I.	A.	II.	III.	B.	IV.	V.	VI.	
SiO_2 ..	47·26	47·28	47·75	48·28	48·34	49·60	49·78	50·12	SiO_2
Al_2O_3 ..	22·80	21·11	19·46	20·38	20·10	15·06	18·82	15·98	Al_2O_3
Fe_2O_3 ..	2·21	3·52	2·31	1·78	1·97	5·29	5·58	4·91	Fe_2O_3
FeO ..	5·41	3·91	6·28	6·70	6·62	5·00	4·85	6·31	FeO
MgO ..	7·76	8·06	7·90	7·93	5·49	4·44	4·15	4·43	MgO
CaO ..	10·93	13·42	11·32	11·80	13·16	9·69	10·40	10·86	CaO
Na_2O ..	1·72	1·52	2·46	1·75	1·66	2·62	3·04	3·60	Na_2O
K_2O ..	0·29	0·29	0·24	0·14	0·98	0·70	0·56	0·70	K_2O
$H_2O > 105°$	0·90	0·53	0·50	0·76	0·44	1·29	1·35	0·53	$H_2O > 105°$
$H_2O < 105°$	0·11	0·13	0·18	0·09	0·02	2·65		0·46	$H_2O < 105°$
TiO_2 ..	0·38	0·28	0·43	0·23	0·95	2·38	1·34	1·76	TiO_2
P_2O_5 ..	0·06	trace	0·62	0·02	0·04	0·29	trace	0·08	P_2O_5
MnO ..	0·31	0·15	0·17	0·28	0·32	0·19	0·28	0·18	MnO
CO_2 ..	0·10	—	trace	0·03	0·11	0·44	—	0·21	CO_2
FeS_2 ..	0·00	—	0·16	0·04	0·00	0·00	0·00	0·05	FeS_2
Fe_7S_8 ..	0·00	—	trace	0·00	—	—	—	—	Fe_7S_8
SO_3 ..	—	—	trace	—	—	0·40	0·00	trace	SO_3
Cr_2O_3 ..	—	—	0·05	—	—	0·02	0·00	0·04	Cr_2O_3
(Co, Ni)O ..	0·00	—	—	0·00	0·00	0·00	—	—	(Co, Ni)O
BaO ..	0·00	—	—	0·00	0·10	trace	0·03	0·04	BaO
Li_2O ..	0·00	—	trace	0·00	0·00	trace	—	trace	Li_2O
C	—	—	—	—	—	—	traces	—	C
Organic matter ..	—	—	—	—	—	trace	—	—	Organic matter
	100·24	100·20	99·83	100·21	100·30	100·06	100·18	100·26	

I. (21250; Lab. No. 735.) Biotite-eucrite. Ring-dyke, Centre 3, Ardnamurchan. Bank of stream, 1 mile E. 33° S. of Achnaha. *Anal.* E. G. Radley.

A. (8194; Lab. No. 19.) Olivine-gabbro. Major Intrusion. Coir' a' Mhadaidh, Cuillins, Skye. Quoted from A. Harker, 'Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 103. *Anal.* W. Pollard.

II. (22821; Lab. No. 790.) Hypersthene-gabbro. Ring-dyke, Centre 2, Ardnamurchan. In side of hollow ¼ mile W. 33° S. of Trigonometrical Station at 1123 ft., Beinn na Seilg, and 1000 yds. E. 27° N. of

Trigonometrical Station at 742 ft., Beinn nan Codhan. *Anal.* B. E. Dixon.

III. (21251; Lab. No. 736.) Gabbro-variant of Great Eucrite Ring-dyke, Centre 3, Ardnamurchan. W. side of Creag an Airgid, 1¼ miles S. 40° E. of Achnaha. *Anal.* E. G. Radley.

B. (14846; Lab. No. 373.) Olivine-gabbro. Major Intrusion, Beinn na Duatharach. ⅝ mile N.N.W. of summit of Beinn na Duatharach, Mull. Quoted from 'The Tertiary and Post-Tertiary Geology of Mull, etc.,' *Mem. Geol. Surv.*, 1924, p. 24. *Anal.* E. G. Radley.

IV. (21254; Lab. No. 738.) Porphyritic Dolerite. Major Intrusion in vent, Centre 1, Ardnamurchan. In stream bank 700 yards S. 19° E. of Trigonometrical Station at 1729 ft., Ben Hiant, and ½ mile W. 24° N. of Bourblaige. *Anal.* B. E. Dixon.

V. Porphyritic Dolerite. Major Intrusion (same as preceding). E. slope of Ben Hiant. *Anal.* Harcourt Phillips.[1]

VI. (22827; Lab. No. 791.) Quartz-gabbro. Ring-dyke, Centre 3, Ardnamurchan. In gorge of Amhainn Chrò Bheinn, 700 yds. E. 30° N. of where Kilchoan–Achnaha road crosses the stream. *Anal.* B. E. Dixon.

THE PORPHYRITIC CENTRAL MAGMA-TYPE

This magma-type in Mull[2] was mainly responsible for a large series of porphyritic lavas and minor intrusions, but found expression in relatively few major intrusive masses. In Ardnamurchan, however, the reverse is the case. This magma is there dominant and is responsible for all the gabbros of Centres 1 and 2 and for much of the great eucritic mass that is the most important intrusion of Centre 3 (*see also* p. 92). Minor intrusions and lavas belonging to this type are, however, poorly represented, the most noteworthy being the porphyritic basic cone-sheets of Centres 2 and 3.

In Mull this magma-type was associated with the Non-porphyritic Central Magma-Type on two important occasions, first as lavas and secondly as cone-sheets. Earlier lavas and earlier cone-sheets were of plateau basalt composition. It is worth noting that in Ardnamurchan the Porphyritic Central Magma-Type followed closely upon the plateau lavas, manifesting itself as one of the earliest intrusive bodies (Ben Hiant Porphyritic Basalt).

The special characteristic of this magma-type is an early separation of basic plagioclase felspar, which gives to the finer-textured rocks a marked porphyritic structure. This feature may be masked to some extent in the plutonic rocks of gabbroid texture but is always pronounced in their finer grained and presumably more quickly cooled marginal portions.

The essential minerals of the type are basic plagioclase felspar, augite and subordinate iron-ore, while olivine and rhombic pyroxene are occasionally important. As pointed out in the Tertiary Memoir on Mull, when compared with what we have called the Normal Mull Magma-Series, the outstanding feature is the relatively high percentages of Al_2O_3 and CaO in rocks of similar silica-content, which is the natural consequence of the early separation and concentration of basic plagioclase.

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[1] Supplied by Dr. A. Harker.

[2] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 23.

The suite of analyses carried out on Ardnamurchan rock-types has enabled us to demonstrate that in this magma-type the values for CaO and Al_2O_3, and the concentration of the anorthite molecule, continue to increase with a falling silica percentage. Thus, its

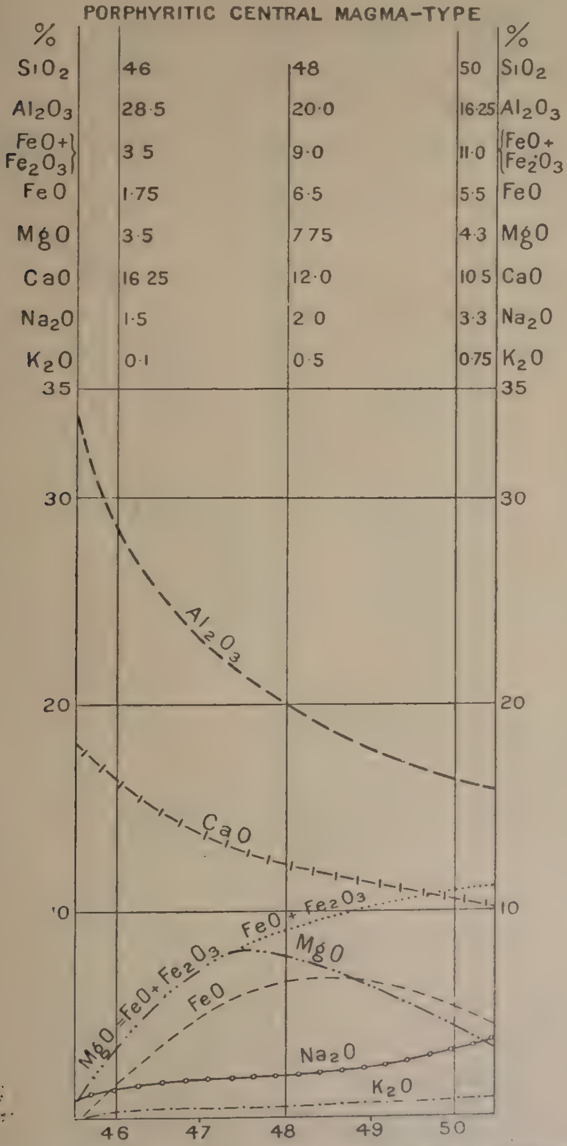

FIG. 7.—*Variation Diagram, Porphyritic Central Magma-Type.*

most basic representative, as argued by Bowen,[1] will presumably have an anorthositic composition. Such a view is supported by the occurrence of anorthositic bands and patches in the Great Eucrite of Centre 3 (pp 295–6).

Corresponding to the obviously related rise in the percentages of CaO and Al_2O_3 is a fall in all the other oxidic constituents but more particularly of MgO and FeO. It will thus be seen that the extreme basic representatives of this magma-type differ markedly from those of other collateral magmas in seldom exhibiting a concentration of either iron-ore or ferromagnesian silicates.

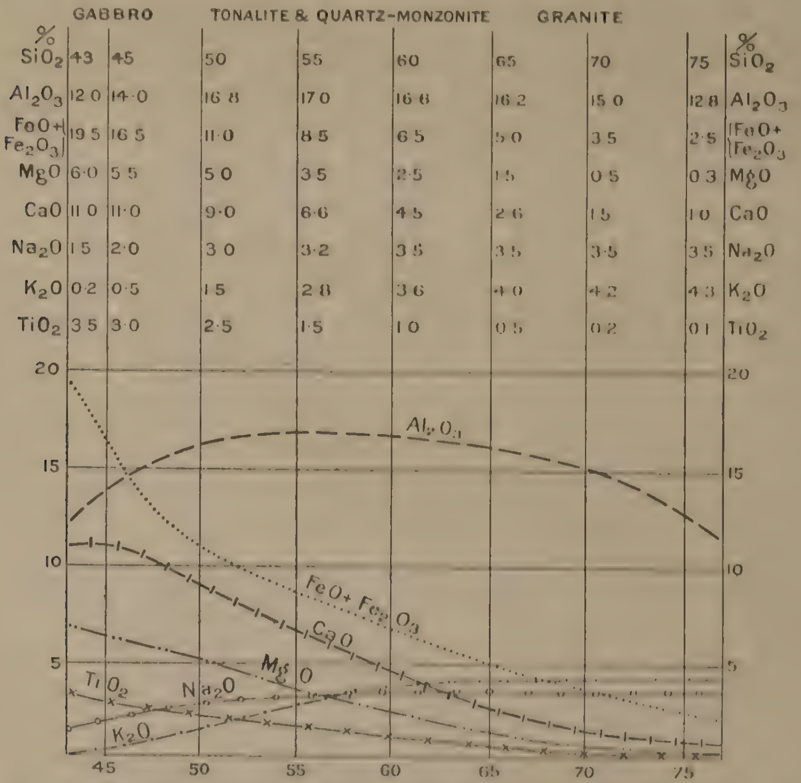

FIG. 8.—*Variation Diagram, Tonalite and Quartz-monzonite Magma-Series.*

With the increase of SiO_2 towards a percentage of 50 the magma takes on a special type of crystallization, which results in the separation of early-formed plagioclase felspar, augite and iron-ore, and subordinate olivine, from a liquid residuum that is supersaturated as regards silica. With such a composition the magma, at a certain stage of its crystallization, is clearly capable of yielding by mechanical separation a partial magma of acid character, which will approximate closely to the acid end-members of other magma-series. Further, at or about this silica percentage the porphyritic type will of necessity lose much of its individuality, and such would possibly account for its apparently limited extension in the acid direction.

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[1] N. L. Bowen, "The Problem of the Anorthosites,' *Journ. Geol.*, vol. xxv., 1917, p. 209; *also* 'The Origin of Ultra basic and related Rocks,' *Amer. Jour. Science*, vol. xiv., 1927, p. 89.

TABLE V

TONALITE AND QUARTZ-MONZONITE MAGMA-SERIES (*see* Fig. 8)

	GABBRO.	TONALITE–QUARTZ-MONZONITE.				GRANITE.			
	I.	II.	A.	B.	III.	C.	D.	E.	F.
SiO_2	44·50	51·59	54·00	54·20	59·16	68·15	70·48	73·09	75·65
Al_2O_3 . .	13·00	16·76	13·09	15·73	16·50	15·95	14·24	14·15	11·89
Fe_2O_3 . .	8·25	2·26	3·53	3·67	3·23	0·74	3·72	0·70	1·19
FeO	9·97	7·49	8·45	5·40	3·66	3·24		1·03	1·02
MgO . .	6·31	3·85	3·49	3·40	2·70	0·04	0·40	0·47	0·15
CaO . .	11·10	7·41	5·55	8·50	4·40	1·88	1·48	1·04	0·91
Na_2O . .	1·88	3·04	3·27	3·07	3·66	3·40	3·66	3·76	3·44
K_2O	0·25	1·95	1·80	4·42	3·72	5·00	4·26	4·21	4·26
$H_2O > 105°$	0·83	1·36	1·71	0·50	0·83	0·22	1·59	0·70	0·40
$H_2O < 105°$	0·29	0·30	1·26		0·44	0·65		0·60	0·41
TiO_2	2·90	2·15	2·83	0·40	1·21	0·20	—	0·22	0·28
P_2O_5 . .	0·06	0·66	0·31	0·50	0·28	0·12	—	0·09	0·16
MnO . .	0·49	0·40	0·37	0·70	0·27	trace	—	0·00	0·26
CO_2	0·14	0·79	0·25	—	0·08	0·00	—	0·00	0·09
FeS_2	0·00	0·00	0·14	—	0·00	—	—	—	0·00
Fe_7S_8 . .	0·00	0·00	—	—	0·00	—	—	—	—
(Co, Ni)O	0·00	0·00	0·00	—	0·00	—	—	—	0·02
BaO	0·00	0·00	0·02	—	0·00	—	—	—	0·03
Li_2O	0·00	0·00	trace	—	0·00	—	—	—	0·00
	100·06	100·01	100·07	100·49	100·14	99·59	99·83	100·06	100·16

I. (21249; Lab. No. 734.) Fluxion Biotite-gabbro. Glendrian Ring-dyke, Centre 3, Ardnamurchan. Ridge ¾ mile E. 17° S. of Achnaha, *Anal.* E. G. Radley.

II. (21248; Lab. No. 733.) Tonalite. Ring-dyke, Centre 3, Ardnamurchan. Knoll at edge of moss ⅛ mile W. 33° S. of Glendrian. *Anal.* E. G. Radley.

A. (24459; Lab. No. 828.) Quartz-dolerite. Garbad sill, Arran. Gorge in Allt Dhepin, ⅓ mile E.N.E. of Trigonometrical Station at 873 ft. O.D., Cnoc an Fheidh, Whiting Bay. Quoted from G. W. Tyrrell, 'The Geology of Arran,' *Mem. Geol. Surv.*, 1928, pp. 147-148. *Anal.* E. G. Radley.

B. Monzonite. Monzoni, Tyrol. Quoted from W. C. Brögger, 'Die Eruptivgesteine des Kristianiagebietes. II. Die Eruptionsfolge der triadischen Eruptivgesteine bei Predazzo in Südtyrol.' Kristiania, 1895, p. 24. *Anal.* V. Schmelck.

III. (21247; Lab. No. 732.) Quartz-monzonite. Boss, Centre 3, Ardnamurchan. Small summit in low ground ½ mile E. of Achnaha. *Anal.* E. G. Radley.

C. Hornblende-granite. Granite 1, Mourne Mountains. Eagle Rock, N.N.W. of Slieve Donard. Quoted from J. E. Richey, *Quart. Journ. Geol. Soc.*, vol. lxxxiii., 1928, p. 660. *Anal.* W. H. Herdsman.

D. Biotite-granite. Base of Slieve na Glogh, Carlingford. Quoted from S. Haughton, *Proc. Geol. Soc. London*, vol. xii., 1856, p. 194.

E. Biotite-granite. Granite 4, Mourne Mountains. Spur east of Finlieve, about 5 miles E. by N. of Rostrevor. Quoted from J. E. Richey, *op. cit.* *Anal.* W. H. Herdsman.

F. (24454 ; Lab. No. 824.) Granophyric granite. Central Ring Complex, Arran. Quarry in Allt nan Dris, 1000 ft. north of Derenenach. Quoted from G. W. Tyrrell, *op. cit.*, pp. 192–193. *Anal.* E. G. Radley.

THE ARDNAMURCHAN TONALITE AND QUARTZ-MONZONITE MAGMA-SERIES

Certain plutonic intrusions that occur as inner members of the Ring-dyke Complex of Centre 3 exhibit mineralogical characters that distinguish them from all the other plutonic rocks of Ardnamurchan. Their chief peculiarity is the development of hornblende, biotite and pyroxene, with plagioclase, alkali-felspar and quartz, a mineral assemblage that gives rise to biotite-gabbro and rocks of tonalitic and monzonitic affinities. These rocks we regard as having been produced from a special magma-type that we have designated Tonalite and Quartz-monzonite.[1] The biotite- and hornblende-granites of Carlingford and the Mourne Mountains may be representative of its acid development.

Compared with other magma-series the Tonalite and Quartz-monzonite Series shows a marked difference in the relative concentrations of the oxidic constituents, more especially of Al_2O_3, Iron, and the Alkalis. It has a wide silica range but, as might be expected, exhibits the most definite characteristics in its basic development.

Compared with the Normal Magma-Series (Fig. 6) the Al_2O_3 is higher over most of its range, though never reaching the altitudes attained by this constituent in the Porphyritic Central Type, and falls rapidly towards the basic end of the series. The Total Iron although mainly comparable to that held by the more acid members of the Normal Series becomes strongly concentrated towards the basic end, a concentration that is shared by MgO and TiO_2. The Alkalis exhibit a tendency, as is in accord with monzonitic and tonalitic rocks in general, to show a continued preponderance of K_2O over Na_2O from the acid well towards the basic end. Thus, whereas the ratio $Na_2O : K_2O = 1$ is reached in the Normal Series at a silica percentage of 68, the same ratio is attained in the case of the magma-type under discussion at a silica percentage of about 58.

At the basic end of the series the high content of Iron and TiO_2, considered in connexion with falling CaO and Al_2O_3, points to the concentration of magnetite, ilmenite, and non-aluminous ferromagnesian minerals rich in the enstatite and fayalite molecules. Such curves as are based upon the analyses of Ardnamurchan and other Tertiary rocks point to the extreme basic end of this series being represented by rock-types comparable with ilmenite-gabbros or ilmenite-norites,[1] towards which the percentages of TiO_2, MgO and Iron continue to rise while those of Al_2O_3, CaO and the Alkalis continue to fall (Fig. 8). Such a magma-series with such variation may be claimed to account for a not inconsiderable proportion of the major plutonic phases of the Tertiary magma.

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[1] The names applied to the various magma-types, and as used here and in the 'Tertiary Mull Memoir,' always carry an implicit geographical significance. When we speak, for instance, of the Tonalite and Quartz-monzonite Magma-Series, such appellation is intended to refer merely to the Ardnamurchan, or at any rate to the British, Tertiary suite.

A similar magma-series, subject to similar variation, it will be remembered, is responsible for the bulk of the plutonic intrusions of Lower Old Red Sandstone age in Scotland.[2]

THE EUCRITE–ALLIVALITE MAGMA-SERIES

This series in Mull, Skye, and especially Rum was responsible for important plutonic intrusions. In Ardnamurchan it is represented by parts of the Great Eucrite, Outer Eucrite, and the less important Inner Eucrite of Centre 3, and by the Beinn nan Ord Eucrite of Centre 2.

The variation in composition exhibited by some of the larger gabbroid intrusions, such as the Great Eucrite of Centre 3 and the Hypersthene-gabbro of Centre 2, makes it quite clear that the Eucrite-Allivalite and Porphyritic Central Magma-Types are closely related. For example, it is usual for the normal facies of the Great Eucrite to be associated with, or pass into, rocks much richer in olivine and anorthite on the one hand, and, on the other, into less basic types that carry augite as the dominant ferromagnesian mineral and a less basic plagioclase. It would appear, therefore, that a gabbro-magma of Porphyritic Central Type is capable of giving rise to two sets of basic differentiates, one set passing through eucrite to allivalite, and the other having anorthosite as its end-member. Such a divergence would be effected chiefly by the impoverishment or enrichment of the magma by early-formed olivine and basic plagioclase felspar.

The two divergent branches are respectively characterized by a concentration of CaO and Al_2O_3 in the case of the anorthosites, and of MgO in the case of the more peridotitic and allivalitic types.

THE ALKALINE MAGMA-SERIES

The Alkaline Magma-Series of Mull, which there was responsible for mugearites, alkali-syenite, trachytes, and bostonites, is only represented in Ardnamurchan by a certain early development of trachytic rocks (pp. 133, 137) that occur in the vent-agglomerates of Centre 1, and by a few occasional dykes of bostonitic composition (p. 355). The outstanding feature of this magma-type is the relatively great concentration of the Alkalis, which is responsible for an abundance of alkali-felspar and, in extreme cases not developed in Ardnamurchan, for the presence of soda-rich amphiboles and pyroxenes, and the occurrence of nepheline.

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[1] A. Harker, 'Natural History of Igneous Rocks,' 1909, p. 142 (Ekersund–Soggendal).

[2] A. Harker, *op. cit.*, pp. 127–131.

The view that this magma is descended from the plateau magma is supported by the already-mentioned alkaline segregations encountered in certain of the plateau basalts, and will be discussed more fully in the following remarks on the probable cause of differentiation (p. 100).

THE MAGMA-SEQUENCE AND COURSE OF DIFFERENTIATION

The magma-sequence of Ardnamurchan subsequent to the extrusion of the plateau lavas presents many points in common with that observed in Mull, and a similar course of magmatic differentiation is indicated. The sequence for Ardnamurchan, exclusive of dykes, is set out below in tabular form :—

	Intrusion-Type.	Rock-Type.	Magma-Type or -Series.
Centre 1	Volcanic Vents	Trachytic and more acid types.	Alkaline and Normal Acid Types.
		Inninmorite-Pitchstone. Big-felspar Basalt.	Normal Sub-acid and Porphyritic Central Types.
	Major Intrusions partly as Ring-dykes	Olivine-gabbro. Quartz-gabbro. Porphyritic Dolerite. Subsidiary Granophyre	Non-Porphyritic and Porphyritic Central with subordinate Normal Acid Types.
	Cone-sheets and Ben Hiant Intrusion	Quartz-dolerite with quite subsidiary acid rocks.	Non-porphyritic Central and Normal Acid Types.
Centre 2	Cone-sheets ..	Non-porphyritic Quartz-dolerite with quite subsidiary acid types. Porphyritic Quartz-dolerite at end of phase.	Non-porphyritic Central and Porphyritic Central Types.
	Ring-dykes ..	Hypersthene-gabbro. Quartz-gabbro. Subsidiary Granophyre	Porphyritic Central with subordinate Normal Acid Types
	Cone-sheets ..	Porphyritic Quartz-dolerite and Basalt.	Porphyritic Central Types.
	Ring-dykes ..	Eucrite. Quartz-gabbro.	Porphyritic Central Type.
Centre 3	Ring-dyke ..	Quartz-gabbro.	Mainly Porphyritic Central Type.
	Cone-sheets ..	Porphyritic Quartz-dolerite and Basalt.	
	Ring-dykes ..	Eucrite.	
	Ring-dykes of Interior Complex	Quartz-biotite-gabbro. Fluxion Biotite-gabbro. Tonalite. Quartz-monzonite.	Tonalite and Quartz-monzonite Series.

It will be seen from the above that there has been a recurrence and repetition of magmatic types at various periods in the igneous history of Ardnamurchan and that there is evidence of three cycles of igneous intrusion. At the outset we have the clearest indication of the uprise of centrally disposed magma to within a relatively short distance from the surface, where the magmatic pressure was sufficient to break through the remaining crust with the formation of vents and vent-agglomerates. That the magma responsible was in an advanced state of differentiation is proved by the nature of the material entering into the composition of the agglomerates and by the composition of the lavas and intrusions associated with the vents. There is reason for assuming that the magma occupied a cupola-like upward extension of the main basaltic magma-reservoir, situated in a cool portion of the crust, in which differentiation by crystallization was progressing. There is, further, indication that the main body of the magma filling this subsidiary reservoir had been reduced to complementary layers corresponding to the Non-porphyritic and Porphyritic Central Types of composition. An acid differentiate, probably of subordinate amount and charged with volatile constituents, occupied the upper part of the cupola. During the vent-period the more basic differentiated magmas found means of expressing themselves as the Pitchstone lavas and Big-felspar Basalt of Ben Hiant.

The dissipation of excessive magmatic pressure responsible for the vents of Centre I was presumably followed by a period of crustal subsidence that allowed the Central Type of magma to be intruded as ring-dykes, and other centrally disposed masses, from lower regions of the subsidiary magma-reservoir.

There is little doubt that the bulk of the magma available towards the end of the period represented by Centre I was of non-porphyritic quartz-dolerite composition, and this was responsible for the early massive cone-sheets and the big intrusion of Ben Hiant. Magmatic pressure at this stage within the reservoir had increased considerably and there was an effort on the part of the magma to raise its roof. This effort was in part successful, for we notice definite doming of the country rock and the intrusion of a second series of cone-sheets referable to Centre 2, which are indications of the yielding of the crust to upward pressures.

It is during such a period of upward stress that the adjustment of crustal stability to magmatic pressure is most critical, and during which the locus of the summit of the intercrustal reservoir is most likely to shift its position. We thus find the locus moving in a west-south-westerly direction for a distance of no less than three miles, and taking up its position at Centre 2. From the calculated depth of the cone-sheet foci in the respective centres it would appear that the summit of the cupola marked by Centre 2 stood at a slightly lower intercrustal level than that previously reached in Centre I.

The igneous activity connected with Centre 2 divides itself into two cycles both commencing with the intrusion of a suite of cone-sheets, and followed by ring-dyke intrusions of Central Magma-Types (Gabbros and Eucrite). The effect of differentiation is obvious also in the cone-sheets themselves, for starting as quartz-dolerites of the Normal Magma-Series they gradually develop in their later representatives characters that link them with the Porphyritic Central Types.

The last intrusive cycle is heralded by another, but smaller, displacement of activity to Centre 3, and the available magma appears to be of Porphyritic Central Type accompanied by an acid differentiate that by admixture and reaction in the later stages of intrusion was responsible for the tonalite and quartz-monzonite masses that occupy the centre of the complex.

The main difficulties that have to be overcome in presenting any scheme of differentiation applicable to a petrographical province are twofold. First, the recognition of a parent magma and the production of the magmatic variation necessary for the formation of the observed rock-types, and secondly of explaining the observed order of extrusion or intrusion of the respective igneous masses. If we allow, as I think we must from the evidence of crystallized melts, that magmatic variation is primarily brought about by fractional crystallization and the removal or concentration of certain less soluble constituents, we are frequently confronted by opposing evidence offered by the order of magmatic expression. It has been proved that the two great magmatic cycles recognized in Mull commenced with a manifestation of the Plateau Magma-Type, which gave place to increasingly acid types as the presumed differentiation progressed; and the same order of decreasing basicity appears to be generally applicable to every other Tertiary centre where complete cycles are represented. Let us first turn our attention to a consideration of the development of the various magma-series and the rock-types for which they are responsible.

The Normal Magma-Series.—In the Brito-Icelandic province the great bulk of rocks attributable to the Plateau Magma, its early and widespread manifestation and its reappearance at repeated intervals, cause us to regard it as the most probable common ancestor of the other magma-types and collateral magma-series. There can be no question that the Plateau Magma was responsible for the earliest and greatest expression of Tertiary igneous activity and that it continued to appear, and is even still appearing, within the limits of the province.

The course of variation of the main magma-series of Ardnamurchan is expressed graphically by the three figures given above, and these may be supplemented by those given in the Tertiary Mull Memoir to illustrate respectively the alkaline and eucrite-allivalite magma-types.

From an examination of rapidly cooled rocks with porphyritic or phenocrystal structure, the order of solubility of different minerals as proved by heterogeneous holocrystalline masses, and the evidence supplied by crystallized artificial melts, we have been able to equip ourselves with much information that has a direct bearing upon the question of magmatic variation. Such information as is furnished by those rocks with low silica percentages from the Tertiary province may be summarized by the statement that olivine, iron-ores, and basic plagioclases are often the least soluble magmatic constituents, and that with falling temperature they begin to crystallize at a very early stage. We have therefore in this fact alone, provided the early crystalline phases can be mechanically transferred from one part of the magma to another, ample means of accounting for at any rate the preliminary stages of magmatic variation.

Viewed in this light and assuming that the Plateau Magma is the parent stock, the Normal Mull Magma-Series presents no great difficulties. It is obvious that if we initially abstract iron-ores, olivine, and basic plagioclase, and follow this by the abstraction of other crystalline phases such as augite and less basic plagioclase, we can produce just such a progressive variation in magmatic composition as is represented by the sequence of increasingly siliceous magma-types. The partial extraction of such crystalline phases from a magma of plateau type, on account of the silica being generally more than is necessary for the formation of the basic ferromagnesian silicates and basic plagioclase, produces a rapid relative concentration of silica and alkalis; and a composition would soon be reached which would find expression as quartz-doleritic rocks with an acid mesostasis capable of mechanical separation and a separate existence as acid lavas or intrusions.

Since the publication of the memoir on Mull many references have been made to the evidence that this region has been able to contribute to the general problems of petrogenesis. Quite recently, in fact after much of the present Memoir had been written, a most valuable contribution has been made to petrographical literature by Dr. N. L. Bowen[1] of the Geophysical Laboratory in Washington, in a volume entitled 'The Evolution of the Igneous Rocks.' Making full use of experimental data and coupling these with a careful study of natural occurrences of igneous rocks, he has given us well-reasoned theories of magmatic descent and petrogenesis. His references to Mull and the British Tertiary Province as a whole are numerous, and he has considered in detail the origin and mutual relationships of the Mull magma-types. In dealing with the crystallization of a basaltic magma he, like ourselves, lays great stress upon the importance of the early separation of plagioclase and pyroxene, and at a still earlier stage of olivine, as petrogenetic factors.[2] In the early separation of olivine and its removal from the sphere of influence of the magma in which it was formed and with which it would continuously react, he sees a magmatic source of free silica. When critically discussing the development of the Non-porphyritic Central Magma-Type from the Plateau Type he has perhaps taken too seriously the suggestion made in the Mull Memoir that such may have been brought about in part by assimilation. He has, however, shown by calculation that the Non-porphyritic Central Magma-Type would arise from the Plateau Type on the separation from it of crystals of olivine and basic plagioclase, and that there is no need for the assimilation of extraneous material.

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[1] N. L. Bowen, 'The Evolution of the Igneous Rocks,' Princeton and Oxford, 1928.

[2] H. H. Thomas, Pres. Address, Sec. C., *Rep. Brit. Assoc.* (Leeds), 1927, p. 56.

He sums up the situation by saying that the determining factor is the continuance of crystallization of olivine until the composition of the liquid is such that it can only be expressed as metasilicate with free quartz. Further, he agrees with us in regarding the procession of magma-types from the Non-porphyritic Central Type, through the Intermediate Types, to the Acid Types of the Normal Magma-Series, as being the direct result of fractional crystallization, mainly connected with the simultaneous crystallization of augite and basic plagioclase.

The Porphyritic Central Magma-Type.—The Porphyritic Central Type of magma is directly deducible from the Plateau Type. It is clear both on microscopic and chemical evidence that the concentration of early-formed crystals of basic plagioclase felspar is the determining factor of the type. It will be readily understood that as the Plateau Magma has a silica percentage of approximately 45, and theoretically pure anorthite 43·2, a large amount of anorthite could be concentrated in the magma without seriously affecting its silica content. It is, however, almost unknown for the porphyritic felspar to have the composition of pure anorthite, for it always contains small but varying amounts of the albite-molecule. The addition of such a basic member of the plagioclases will therefore either leave unchanged the magmatic silica percentage or effect a slight concentration of silica together with that of soda. A still further concentration of silica and alkalis would be the normal result of the removal from the magma, either before or after its enrichment in anorthite, of any of the less siliceous ferromagnesian minerals and iron-ores.

Compared with the original Plateau Magma this enriched magma would show a great concentration of CaO and Al_2O_3, a less obvious but still definite concentration of Na_2O, and, through dilution, a fall in the percentages of MgO, Total Iron, and TiO_2. In order to produce this concentration of CaO and Al_2O_3 and the related falling off of other constituents, the original magma would have to be enriched by some 30–40 per cent. of basic plagioclase.

We have seen that the probable course of variation in the Normal Magma-Series was outlined mainly by the withdrawal of olivine and basic plagioclase. Such crystalline phases could only be removed to greater depths in the magma by the gravitational process of sinking, giving rise to an enriched magma of Porphyritic Central composition. It must be understood that the precipitation of olivines and basic plagioclase need not have been simultaneous throughout the whole early period of magmatic crystallization, nor may these minerals have been separated or resorbed in like proportion, but it will be quite evident that the establishment of a Porphyritic Central Type is the logical sequel to the variation of the Plateau Type towards the other types of the Normal Series.

Such an enriched magma as has been developed, if erupted, would give rise to a quickly cooled rock that would represent the undifferentiated Porphyritic Central Magma, and of such rocks we have many examples in the Porphyritic Central lavas of Mull. These have an average silica percentage of about 47·5, and the composition as indicated for this silica value in Fig. 7 may be taken as being that of the initial magma of Porphyritic Central Type.

If such a magma were intruded into a separate reservoir situated within the temperature limits that permit of crystallization it would differentiate in two directions, towards a basic end by the concentration, and towards an acid end by the withdrawal, of its more basic constituents. Differentiation in the basic direction would, quite reasonably, take place along two lines, both dependent upon the separation of olivine, basic plagioclase, and iron-ore. The accumulation of all these solid phases would give rise to an increasingly basic series that would proceed by way of the eucrites to the allivalites and other peridotitic rocks, while the concentration of felspar, with the withdrawal to depth of olivine and iron-ores, would give rise to a subordinate magmatic branch, responsible, in its most extreme development, for the anorthosites.

Such a type of differentiation is rendered most probable, if not proved, by the constant occurrence of allivalitic, eucritic, and anorthositic patches and veins in the body of gabbro-intrusions of Porphyritic Central Type. That the early differentiates have sometimes solidified is suggested by their occasional occurrence as xenolithic masses and schlieren, but quite frequently the types grade into each other in a manner suggestive of the incomplete admixture of liquid, or partially liquid, magmas. In the acid direction the rapid extraction of basic plagioclase and the basic iron-magnesian silicates allows the crystallization of augite and also soon supersaturates the residual magma as regards silica. This, together with the consequent concentration of alkalis, gives rise to rocks of non-porphyritic quartz-dolerite composition with a mesostasis of alkali-felspar and quartz. The acid mesostasis, the last product of the more acid differentiates to solidify, may under normal conditions be retained in the rock to which it belongs; it may, however, if under stress, migrate and penetrate as veins the already solid rocks in its neighbourhood. Such a process of segregation and migration of acid residual matter is a feature constantly to be observed in connexion with the major intrusions of Porphyritic Central Type.

Dr. Bowen [1] has carefully considered the position of the Porphyritic Central Magma-Type in the scheme of magmatic differentiation, and regards the essential characters of the type as being directly attributable to the process of crystal-sorting, that is to say, to the concentration by mechanical means of one or more early formed solid phases. He will not allow, however, that the various rock-types embraced by the Porphyritic Central Magma-Type are lineally related, for he holds that there were no liquids corresponding in composition to the Magma-Type. His reason for this view is primarily that representatives of the Type are always porphyritic even in their finer crystallizations. Perhaps the statement in the 'Tertiary Mull Memoir,' that a porphyritic structure is 'always' to be observed in the more quickly cooled rocks of the Porphyritic Central Type, is a little too general. At any rate, the proportion of porphyritic individuals is by no means constant and there is frequently a marked increase in the number and size of the crystals as the interior of a mass is approached. On Dr. Bowen's own showing there is nothing inherently impossible in the re-solution of accumulated early formed plagioclase, and that this condition was approximated to, even if not completely attained, is suggested by the great textural differences exhibited by marginal and internal portions of the same rock-mass, and existing between plutonic and hypabyssal representatives of the Porphyritic Central Type.

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[1] N. L. Bowen, 'The Evolution of the Igneous Rocks,' Princeton and Oxford, 1928, p. 134, *et seq.* Dr. Bowen does not altogether exclude the possibility of re-solution of early crystals but considers that he has found limits to its significance: 'Solution of calcic plagioclase never occurs beyond an amount sufficient to endow the liquid with normative plagioclase more calcic than Ab_1An_2' (*op. cit.*, p. 276). This happens to be the normative composition of felspar in two out of the three analyses of lavas of Porphyritic Central Magma-Type published in the 'Tertiary Mull Memoir' III and V of Table VI, p. 24).

Therefore, while admitting the possibility of the Porphyritic Central Magma never having been quite free from solid phases, there appears to be evidence that these, in certain cases, have been reduced to mere nuclei, and that the liquid, in which they later became regrown without serious modification of their composition, was capable of yielding its own suite of differentiates. Towards the basic end these differentiates would be distinct from those of the Normal Magma-Series, but in the other direction the respective descendants of the two magmas would be similar.

It is, however, evident that in many noteworthy cases, such as the fluxion gabbros, representatives of the Porphyritic Central Type were intruded in a partly solid condition, and also that a partly solid magma of this type was necessary for the production of certain plutonic masses of abnormal composition (*e.g.* Tonalite and Quartz-monzonite Series).

The Tonalite and Quartz-monzonite Magma-Series.—When we come to consider the Tonalite and Quartz-monzonite Series as represented in Ardnamurchan we find a certain amount of evidence that militates against its being a normal collateral series produced by the ordinary direct processes of differentiation. A comparison of the variation diagrams set out above shows clearly that the series under discussion is related to the Porphyritic Central Series in its relatively high alumina. At the acid end of the series, however, the compositional characters are similar in a general way to those of the Normal Series. The curves for Total Iron, CaO and MgO are approximately parallel to those for the same constituents in the Normal Series. At its basic end there is a superficial resemblance to the basic end of the Normal Series, especially if the latter were enriched in iron oxides, TiO_2 and MgO by the addition of titaniferous iron-ores and magnesian olivine.

Certain ferromagnesian minerals characteristically appear in rocks of this series and they may either replace or be supplementary to those met with in representatives of the other magma-series;

such minerals as exemplified in the Fluxion Biotite-gabbro, the Tonalite, and Quartz-monzonite, of Centre 3, are hypersthene, hornblende, and biotite, the last-named becoming increasingly abundant as the percentages of silica and potash rise. A review of these analysed rocks, and others to which they are allied, coupled with an examination of certain granophyric masses and veins that have clearly been modified by the assimilation of basic material, strongly suggests that the various members of the Tonalite and Quartz-monzonite Series are due to magmatic admixture or hybridization before intrusion.

It has been found that in the granophyre-veined Quartz-dolerite Ring-dyke of Centre 3, biotite and hornblende are developed, giving rise to tonalitic and monzonitic types as the result of assimilation of basic material. The Biotite-eucrite, which locally is a good eucrite or gabbro, where acidified, develops biotite and hornblende with the formation of more siliceous veins of tonalitic character. Certain portions of the Fluxion Biotite-gabbro of Sìthean Mòr contain much xenolithic basic matter of eucritic nature, and there is ample evidence of acidification of the xenoliths. The Fluxion Biotite-gabbro of Glendrian (analysed) shows the effects of the acidification of a basic rock in all stages. The quartz-biotite-gabbros, too, are occasionally dioritic, with much hornblende, and locally become monzonitic by modification. The same mineralogical peculiarities have been noted over and over again, throughout the whole ring-dyke complex, in the case of acid veins that have penetrated and assimilated basic material. The fact that amongst the larger gabbro masses of the Tonalitic and Quartz-monzonitic suite we have small areas of normal eucrite, olivine-gabbro, and basic rocks either rich or poor in iron-ore, makes it probable that basic representatives of the Porphyritic Central Magma-Type were involved in the production of these rocks.

The general presence of hornblende and biotite in representatives of this series, and the preponderance of K_2O over Na_2O above a silica percentage of 58, point to the influence of an acid differentiate or end-member of a series, in which there had been a considerable concentration of volatile constituents and a somewhat high concentration of potash.[1]

Although of necessity the acid end-product of the Normal Series would be the richer in volatile constituents and would thus most readily fulfil the conditions demanded, it does not appear likely that such a partial magma could be available throughout the intrusive period represented by the Porphyritic Central Types. The evidence of reaction between basic types and what must clearly be regarded as an acid differentiate of the same magma is furnished by the acid veins in most of the basic intrusions, and by certain hybrid masses such as that of Beinn an Leathaid (p. 158).

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[1] *See* N. L. Bowen, 'The Later Stages of the Evolution of the Igneous Rocks,' *Journ. Geol.*, vol. xxiii., Supplement, 1915, p. 41; J. H. L. Vogt, 'The Physical Chemistry of Crystallization and Magmatic Differentiation of Igneous Rocks,' *Journ. Geol.*, 1922, vol. xxx., p. 659; P. Niggli, 'Die gasförmigen Mineralisatoren im Magma,' *Geol. Rundschau*, III, 1912, p. 473.

It therefore seems probable that the tonalitic and quartz-monzonitic rocks are due to the acidification of Porphyritic Central Magma-Types or, conversely, the basification of some acid magma, such magma being the end-member of the Porphyritic Central Magma-Series. It must, however, be pointed out that this conclusion is based wholly upon petrological considerations. The field evidence is summarized on p. 211.

The Alkaline Magma-Series.—The origin of this magma-series lies clearly in the Plateau Magma and is the normal outcome of the latter's crystallization under special conditions. The evidence for the direct connexion of the Alkaline Series and the Plateau Magma is furnished by the alkaline segregations encountered in the lavas and sills of Plateau Magma composition and may be inferred by the frequent presence in rocks of this character of a zeolitic or analcitic base. The members of the Alkaline Series are clearly not normal lineal differentiates of the Plateau Magma, for the Normal Series, so well represented in the Tertiary Province, progresses along a much less alkaline course. The difference is probably to be found in the different conditions of crystallization, and the bulk of the magma involved, whereby a great concentration of volatile constituents and alkalis is effected.[1] I would suggest that the Alkaline Series owes its origin to the more or less complete crystallization of the plateau basalt magma, without the interim withdrawal of solid phases, such as is assumed to account for successive stages in the Normal Series, accompanied by a strong concentration of the volatile constituents. In fact, I regard the alkaline magma as representing the normal alkaline mesostasis of such basic rocks as are formed by the more or less rapid cooling of the undifferentiated plateau magma.

HYBRIDS AND HYBRIDIZATION

In his study of the igneous rocks of Skye Dr. Harker encountered a number of rock masses, both in the plutonic complex and in the composite dykes and sills, which exhibited abnormal composition and presented an unusual mineral assemblage. He recognized that such rocks were due to what might be termed a reversal of the normal processes of differentiation and might arise either from the commingling of two fluid rock magmas or from the reaction between fluid magma and solid rock. He was able to study the veining and acidification of basic rock by acid magma, the inclusion of basic xenoliths and xenocrysts that showed every stage of dissolution, and to show that there was an accompanying basification of the acid magma. To such modified and abnormal rocks he gave the name of Hybrid, and to the processes by which their abnormality was produced, Hybridization.

In Mull a number of rocks exhibited characters that appeared to be abnormal, and certain of these were undoubtedly true hybrids produced by the intrusion and partial assimilation of basic rock by an independent acid magma. In the majority of cases, however, the abnormalities presented, while being of the same general nature as those characterizing hybrids, were produced in a partially consolidated magma by the migration of its own acid differentiate. The authors of the 'Tertiary Mull Memoir' considered that in Mull, at any rate, there was no positive evidence of the commingling of magmas prior to their arrival at the place where they consolidated.

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[1] *See* N. L. Bowen, *ibid.*

There can be no question that the formation of an acid differentiate is the natural outcome of the fractional crystallization of a parental basic magma such as that with which we have to deal. Further, there appears from microscopic evidence to have been a considerable time and temperature interval during which this acid partial magma remained fluid and was capable of migration under stress. It will be readily appreciated that as soon as a magma has become partially solid and a crystalline mesh has formed, uniform hydrostatic pressures no longer operate. The mass, therefore, may be subjected to localized stresses that, by causing varying contraction of the crystalline mesh, may produce unequal distribution of the residual liquid. It is a process such as this that would best account for the great variability of many of those rock-masses which have an acid mesostasis, and also in extreme cases for the separate existence of acid veins and acid minor masses.

When a magma that would yield an ultimate acid differentiate has crystallized under normal conditions, without the mechanical extraction or addition of any crystalline or liquid phase, the constituent minerals show a definite harmonious relation to each other. The felspars and other minerals that form solid solution series exhibit the effects of what Dr. Bowen terms continuous reaction, and which are the results of the composition of the crystals keeping pace, as solidification progressed, with the changing composition of the liquid phase. In such cases there is no widespread exhibition of the results of disturbed equilibria and consequent resorptive processes. Where solid phases, through the migration of an acid partial magma, have found themselves in surroundings inimical to their normal development, there has been a supreme effort to restore equilibrium between them and the liquid phase. Local evidence of this action is forthcoming in the resorption of basic plagioclase, the regrowth of felspar of increasingly alkaline composition, the deschillerization and recrystallization of augite, and in the existence of clots of definitely gabbroic matter swamped by an excess of acid mesostatic material. Mechanical effects are often noticeable in the reduction of the original basic material to a xenocrystal state, the fissuring and albitization of original felspars, the obliteration of ophitic structure, and the bending of columnar augites. Dr. Bowen has considered this condition when dealing with the effects of assimilation,[1] and he brings out the important fact that the mutual changes produced in solid and magma are exothermic. Such changes therefore can be accomplished without demanding that the liquid phase shall be superheated. Such appears to have been the conditions that prevailed in most of the Ardnamurchan quartz-gabbros. In discussing these and related rocks it has been found expedient to use the term hybridization to describe in a general non-committal way the evidence of disturbed and partially restored equilibria frequently furnished by rocks of this class, and it must not be assumed, in such cases, that an independent acid magma has intervened.

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[1] N. L. Bowen, 'The Evolution of the Igneous Rocks,' Princeton and Oxford, 1928, p. 175, *et seq.*

Certain rocks in this Memoir have been described as hybrids with the assumption that either an independent acid magma has reacted with a basic rock, or that co-existing magmas of widely different composition have commingled prior to, or during, their intrusion. Examples of the former class are furnished by composite minor intrusions, such as that of Sròn Bheag, and can be studied in relation to the acid veining of basic rocks by granophyric matter. To the latter class belong the important tonalitic and monzonitic masses of Ardnamurchan. These occurrences, which in some cases can be proved, and in others inferred, to have a hybrid nature, are linked together by the presence of biotite and hornblende among their mineral constituents. Dr. Bowen[1] regards the formation of these two minerals as the natural result of slow crystallization of basaltic magma where the conditions admit of zoning or crystal sorting of the early calcic felspars with a consequent concentration of alkalis, especially potash, in the liquid residuum. In the Tertiary rocks of the Hebrides we can cite no basic or intermediate rocks belonging to the Normal Magma Series or of Porphyritic Central Type that carry either biotite or hornblende as unquestionably original constituents, and thus differentiation of the Hebridean Magma appears to have followed a different course.

The fact that biotite and hornblende are very sparingly developed as the result of interaction between the normal acid mesostasis of the quartz-gabbros and their pyroxenic constituents, but are prevalent where these or similar rocks are traversed by acid veins from an external source (*e.g.* Sròn Bheag Intrusion), is of considerable significance. It furnishes evidence for regarding the dominantly biotitic and hornblendic rocks of Ardnamurchan as hybrids.

H.H.T.

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[1] N. L. Bowen, *op. cit.*, pp. 79-91.

CHAPTER IX

TERTIARY BASAL SEDIMENTS, ARDNAMURCHAN

WITH the exception of a little Cretaceous *remanié*, Inferior Oolite, with probably a few feet of Great Estuarine Series, is the latest Mesozoic rock preserved in Ardnamurchan. Inferior Oolite is found *in situ* south-west of Kilchoan Bay and as blocks in a volcanic neck at Achateny, on the north coast. In exposures on the north side of Ben Hiant, and in others south-east of Loch Mudle, nothing later than the bottom Pabba Beds of the Lower Lias has been preserved beneath the Tertiary. In much of the country east of Ben Hiant, basal Tertiary sediments rest directly on Moine Schists. Thus, in a distance of about five miles, the Tertiary transgresses some 700 ft. of Jurassic strata.

In Morven, south of Ardnamurchan, Prof. Judd found Upper Cretaceous fairly widely distributed. It there succeeds Lower Lias—Broadford Beds or Pabba Beds, according to locality. In south-eastern Mull, Upper Cretaceous lies directly on Lower Lias and Inferior Oolite; in southern Mull, on Middle and Upper Lias; in western Mull, on Rhætic and Lower Lias. It is clear, therefore, that early Cretaceous erosion removed large thicknesses of Jurassic strata from Morven and Mull. At one point in Ardnamurchan, Mr. Simpson has found what he regards as *remanié* Chalk flint, along with a shark's tooth, embedded in a basal Tertiary coal that rests directly on schist. If it be correct to interpret this Upper Cretaceous material as practically untravelled, it would seem as if, here too, the Jurassic had been eroded during early Cretaceous times.

In Ardnamurchan, as in Morven and Mull, the Tertiary lavas almost invariably rest upon a few feet of Tertiary mudstone—too thin to show separately on the published maps. Other Tertiary deposits locally occur below the mudstone. The latter is of a red or greenish colour, and is usually fine in grain, though in places it contains recognizable angular volcanic material. Rounded grains of quartz are often scattered through it. These may have been derived from deposits of either Upper Cretaceous or pre-mudstone Tertiary age, for sandstones of these two dates, in Morven and Mull, frequently contain wind-rounded grains.[1] The origin of the mudstone has already been discussed by Mr. Bailey in the Tertiary Memoir on Mull.[2] Following upon a suggestion by Dr. Lee, he ascribed the mudstone to lateritic decay, under warm, moist, climatic conditions, of a widespread basaltic ash. The admixture with sand grains in Ardnamurchan points to some resorting of the original ashy material. A further indication of this is the frequently bedded appearance of the upper part of the mudstone coupled with the occurrence of a band of ironstone, resembling an impure clayband, interbedded in the deposit west of Sròn Bheag, south-west of Kilchoan.

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[1] E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 54-57, and 'Pre-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1925, pp. 116, 117.

[2] E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 53, 54.

For geographical convenience the area will be described from west to east.

Sròn Bheag.—An exposure of Tertiary resting on Inferior Oolite may be visited at low tide, 350 yds. west of a projecting portion of Sròn Bheag, 1¾ miles south-west of Kilchoan. Here a high sea-cliff, of which the upper portion is composed of basalt lava, has slopes of talus and landslip extending half-way up, and at their western end Tertiary sediments can be hammered for three feet below the basal lava. Farther down the cliff, the sediments are inaccessible, but may be examined among fallen debris on the shore below.

The mudstone is present in its usual position below the basalt lavas, and includes near its top an intercalated bed of ironstone, 2 inches thick. Above the ironstone the mudstone is fine-grained, fissile and purple, while below it is more ashy looking and contains rounded quartz grains.

The mudstone rests on a thin-bedded white sandstone, fallen fragments of which are loose-textured and uniformly fine. Contact alteration by Tertiary intrusions has obscured the original form of the quartz grains in this sandstone, but the rock certainly differs in type from the reddish close-textured, more massive sandstone of Inferior Oolite age that underlies it, and it may thus belong to the Tertiary. A highly baked white sandstone, of the same type as that just described, outcrops next to basalt lavas immediately south of the gabbro complex, south-west of the twin lochs that lie south-east of Beinn na Seilg.

Glebe Hill. Tertiary lavas form the greater part of Glebe Hill, north of Kilchoan Bay. At their northern extremity, just south of a stream named Amhainn Chrò Bheinn on Sheet 52, these lavas are separated from adjacent gabbro by a narrow outcrop of highly granulitized rocks, consisting of sediments and intrusions. The sediments include baked sandstone and a sapphire-spinel rock which may represent the Tertiary basal mudstone, intensely contact altered (p. 235).

Ben Hiant. Sandstones with thin layers of jet occur below ashy-looking basal mudstone on the south slope of Ben Hiant, in a stream that enters the sea half a mile east of Maclean's Nose. Their geological age is quite uncertain. The sandstones show no wind-rounding of their grains, such as is characteristic of the Tertiary sandstones of Mull. On the other hand, they contain pebbles and angular fragments of quartz and schist, and thus resemble Trias conglomerate, an outcrop of which may be seen in another stream 200 yds. to the north-east. They lack, however, the characteristic red colour of Trias, and in addition to layers of jet they include obscure plant-remains. No exactly similar beds have been found in any other section in Ardnamurchan. Possibly they may be the equivalents of Tertiary beds, including a coal exposed farther east, to be described later.

The section is as follows :—

		Ft.	In.
	Red mudstone (TERTIARY)	1	0
Age Doubtful	Coarse yellow sandstone with quartz pebbles and angular fragments of schist	2	6
	Fine buff-coloured sandstone	3	0
	Dark sandy shale and shaly sandstone with obscure plant-remains	0	6
	Sandy dark bed with lenticular layers of jet ..	0	6
	Light grey marl	0	8
	Gap, not more than	1	0
	MOINE SCHIST	–	–

The mudstone also outcrops in streams that join to reach the coast a mile east of Maclean's Nose. In one of these, it succeeds Trias conglomerate, and in the other it rests directly upon Moine Schists.

East of Loch Mudle Fault.—East of Ben Hiant, immediately to the east of the Loch Mudle Fault, Tertiary mudstone, 3 ft. thick, lies directly upon Moine Schists, in a stream 1¼ miles north-north-west of Ardslignish. Northwards from this the stratigraphical gap at the base of the Tertiary diminishes. In a stream, 2¼ miles north-north-west of Ardslignish, Lower Lias, including limestone with overlying shales, intervenes between schists and basalt lavas. The mudstone is here absent, as is also the case in a stream section farther north at the north margin of the Ardslignish lava outcrop, south-east of Loch Mudle. There the basal lava rests directly on Lower Lias, either shales or limestone. J.E.R.

A little farther east, south of the east end of Lochan a' Mhadaidh Riabhaich, conglomeratic sandstone is seen, probably *in situ*. Near by, to the west, 10 ft. of Lower Lias limestone are exposed, but it has not been found possible to determine the age relation of the conglomerate to the limestone. It remains an open question whether the conglomerate is Trias or Tertiary. At the head of a streamlet, 2 miles south-east of Loch Mudle (beyond the eastern margin of the Memoir-map), one inch of carbonaceous sandstone is all that separates lavas and schists; analogy with Mull and Morven makes it certain that this carbonaceous layer is of Tertiary age. Half a mile farther south, blocks of conglomerate are strewn along the base of the lava escarpment, and in one case, half a mile farther south again, 5 ft. of conglomerate are exposed *in situ*. This brings us near the first of the little streams that run across the lava base and drain directly into Loch Sunart. Three of these streams furnish particularly interesting exposures, and are here described, although, like other sections just referred to, they lie outside the eastern margin of the Memoir-map.

The first of the streams just mentioned can be identified on Sheet 52 as entering Camas Fearna at its north-east angle near a cottage. In this stream the section is as follows :—

		Ft.	In.
TERTIARY BASALT LAVAS		–	–
Purple mudstone		4	0
COAL	up to	2	0
Sandy fireclay		–	3
MOINE SCHIST		–	–

The coal was discovered by a local resident during the winter of 1921. It is from 1½ to 2 ft. thick, brown and of poor quality. It sometimes contains a large admixture of beautifully rounded quartz grains, together with chalk flints. The purple mudstone above the coal also includes similar quartz grains in its lower portion.

A search for fossils in the confused upper part of the coal deposit yielded a shark's tooth. This has been identified by Sir Arthur Smith Woodward as belonging to the genus *Oxyrhina*, probably *O. mantelli*, a species of late Cretaceous or early Tertiary age. Its association with the Chalk flints and rounded quartz grains makes it almost certain that it is *remanié* from a pre-existing Upper Cretaceous deposit. Otherwise one must admit a marine Tertiary fossil in the West Highlands where nothing of the kind has previously been discovered. The flints, it may be added, are full of foraminifera that can be seen in microscope slices.

It will be noticed that the conglomerate exposed farther north is absent in this coal-bearing section. It reappears in the next stream to the west, which also drains into Camas Fearna; but here the coal unfortunately is absent, so that the two rocks, coal and conglomerate, are never seen together:—

		Ft.
TERTIARY	Lavas	–
	Mudstone	3
? TERTIARY or TRIAS	Greyish-green conglomeratic sandstone	2
	Conglomerate	3
	MOINE SCHIST	–

The pebbles in the conglomerate consist almost exclusively of well-rounded quartz, and range up to the size of a hen's egg. A few angular fragments of schist occur, but no flint could be found.

The more westerly of the streams entering Camas Ban gives a less complete exposure. Here, 2 ft. of creamy-white sandstone, with occasional pebbles, are capped by mudstone. The base unfortunately is hidden, and nothing more is seen till Moine Schist is reached a little downstream.

Mudstone is visible at low tide beneath the lavas in Camas Bàn. Moine Schist appears close at hand, but there was no continuous exposure at the time of the survey. J.B.S.

CHAPTER X

TERTIARY BASALT LAVAS, NORTH-WEST MULL AND ARDNAMURCHAN

THE basalt lavas described in the present chapter form a portion, or a continuation, of the Plateau Group of Mull.[1] In the case of Mull the area considered falls within Sheet 51, while in Ardnamurchan a portion of Sheet 52 is also included (*see* Memoir-map). Pitchstone lavas, later than the Plateau Group, are found within the Ardnamurchan vents, and their description is reserved for the next chapter.

Over 1000 ft. of lavas are preserved, and most of the flows are olivine-rich basalts without porphyritic felspar—the Plateau Types of Mull. Olivine-poor basalts, of Mull Central Types, with or without porphyritic felspar, occur only as subordinate intercalations. Mugearite and mugearitic basalt are also present.

No evidence has been found to decide whether the Ardnamurchan centre, with its numerous vents and intrusions, functioned during the outpouring of the Plateau Group. The first volcanic event seems to have been the explosion, or series of explosions, that provided material for the widespread basal mudstone described in the previous chapter. The source of these explosions has not been located. The lavas that followed are free from ash intercalations. They may have been poured out from central craters or from fissures. There are many dykes, especially in Mull ; but in the latter locality, at any rate, the dykes form part of a swarm that is grouped with reference to an already established focus. They therefore afford no suggestion of fissure eruptions of earlier date than the focus.

As has been known for a long time, the eruptions were subaerial. There are no intercalated water-borne sediments except a few volcanic clays or muds that have been derived from weathering of the lavas, while contemporaneous weathering, resulting in the formation of red clay or bole, is repeatedly observed. This shows that individual flows were often exposed subaerially for a considerable time before being covered up by subsequent lavas. A bole may be resorted by water and penetrate down as veinlets into an underlying slaggy lava-top.

Terrace or trap featuring characterizes North-west Mull and the lava outliers east of Ben Hiant in Ardnamurchan, especially the Ardslignish outlier east of the Loch Mudle Fault. It is due to the general tendency of individual lavas to have solid interiors and slaggy surfaces, more particularly upper surfaces. The lava sequence thus consists of interbanded solid and slag. Rapid waste of each layer of slag leads to undermining of superincumbent solid basalt, and to the consequent formation of an escarpment. On the Mull coast, cliff-sections afford excellent views of lava-flows piled flatly one upon another. At intervals, stream-gullies allow a closer examination showing individual flows with slaggy or amygdaloidal upper portions, more solid interiors, and, sometimes, slaggy bases.

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[1] E. B. Bailey, *in* 'Tertiary Mull Memoir,' 1924, chap. v. and Pl. iii.

Where trap featuring prevails, the more solid portions of the lavas often retain their olivine in a fresh condition, and they also are apt to weather to a rusty loam, in some cases spheroidally. Another fairly common feature is the development of a pimply surface as a result of weathering.

In the Ardnamurchan outliers north-west of Ben Hiant, trap features are not developed, and olivine is decomposed. These outcrops have been broken by explosions or pierced by intrusions and can scarcely be expected to develop a regular type of scenery. Moreover, they show alteration of their material, partly due to steam and other gases (pneumatolysis) and partly to dry heating. Pneumatolysis has affected to a greater or less degree the lavas in contact with almost all the Ardnamurchan vents excepting those of Ben Hiant, while the rocks actually within the vents are also often altered, and have developed epidote. This alteration is ascribed to vapours derived from the acid magma responsible for the vent explosions. On the other hand, intense contact alteration, accompanied by dehydration, is found in the vicinity of the great gabbro intrusions of Ardnamurchan.

Other points of interest, mentioned in the local descriptions that follow, include: an unconformable contact with an underlying sandstone at Bloody Bay in Mull; segregation veins both in the Mull and Ardslignish outcrops; and an occurrence of pipe amygdales at Ben Hiant. J.E.R.

NORTH-WEST MULL[1]

A typical development of the Plateau Group occupies the north-western corner of Mull. Most of the lavas are olivine-rich basalts with fresh olivine and no porphyritic felspar. They generally show a rude approximation to columnar structure; but, in Beinn Bhuidhe, platy jointing is common, and is probably to be correlated with a somewhat mugearitic composition. An individual flow with sparse felspar phenocrysts forms a conspicuous scarp above the Dervaig-Salen road, 2½ miles south-east from Dervaig. Along with a few other examples it shows an approach to the Porphyritic Central Type of Mull. Another exceptional lava (20949) reproduces the compact Non-porphyritic Central Type of Mull. It overlies a bright red bole, or irony clay, 12 ft. in thickness, which renders the exposure conspicuous in the field, though not easy to locate on the map. The following directions may help. Two streams are shown on Sheet 51 between Beinn Bhuidhe and Càrn Mòr, and the more westerly, 700 yds. north of the map margin, is joined on the west by a tributary (omitted on the one-inch Map). The bole and overlying compact lava occur in a little gorge 300 yds. up this tributary.

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[1] This account is rewritten from the description by J. E. Richey, G. V. Wilson, and G. A. Burnett *in* 'Tertiary Mull Memoir,' 1924, chap. vii.

On examination, the lower portion of the bole is seen to consist of lava rotted *in situ*.

Lava tops, reddened by contemporaneous weathering, are common in the district. A good succession is seen in a ravined coastal cliff, north of the 200 ft. hill that stands east of Treshnish Point. Other good examples occur in the cliff above the road to Calgary pier, between the plantation and the stream that are shown on the one-inch Map. Another is afforded at the base of Dùn Leathan on the coast of Quinish.

Trap or terrace featuring is very general in this lava country, and is well illustrated along the zig-zag road that leads from Dervaig

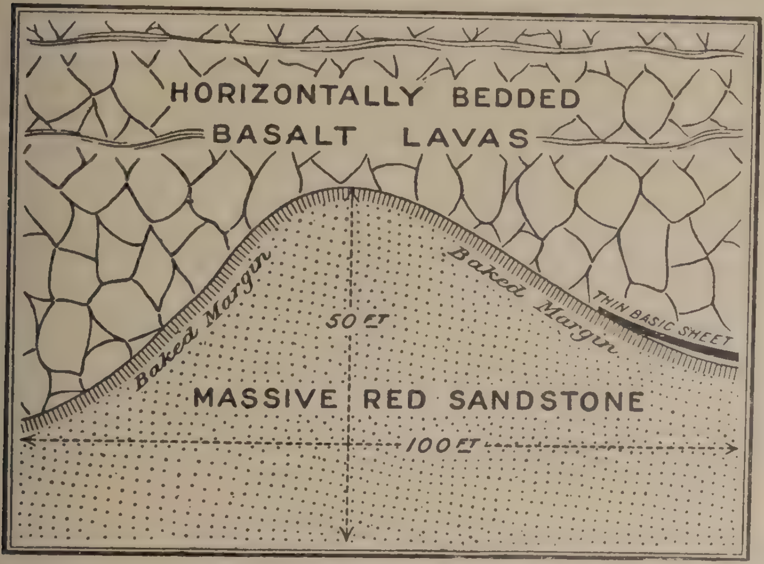

FIG. 9.—*Tertiary basalt lavas overlying a knob of sandstone at Bloody Bay, Northern Mull.*

Quoted from 'Summary of Progress for 1920,' p. 37.

eastwards towards Tobermory. It is due, as already explained, to differential weathering of solid and slag.

The district is scenically divided into two parts by the hollow of Loch a' Chumhainn, on which Dervaig is situated. It can be seen on the one-inch Map that south-west of this line the trap featuring of the lavas is irregular in plan; while north-eastwards it is conspicuously lineated in a north-west and south-east direction. The difference is due to the fact that, north-east of Loch a' Chumhainn, the lavas lie in the course of the great Mull swarm of north-west dykes, and that many of these latter have served as guides to erosion (*see* p. 344).

Only at one place, discovered by the late Prof. Judd, is the base of the lava series exposed. This locality occurs in the cliffs of Bloody Bay, at the eastern margin of the map, 500 yds. east-south-east of Ardmore farm (*see* p. 49). The best exposure is in an old quarry in the cliff face (Fig. 9).

The sandstone in the quarry exposure stands up as a knoll, surrounded and overlain by lava with manifest unconformity. In no other instance known in Mull or Ardnamurchan, do the Tertiary lavas exhibit a comparable irregularity of base, though transgression of the Tertiary lavas across the Mesozoic subdivisions and on to the schists is of course a leading feature of the district. A thin basic intrusive sheet locally occurs at the contact, but in the main the overlying discordant material is lava, not intrusion, for it is associated with slag and shows no trace of marginal chilling.

Three other features of interest may be noted in conclusion. (1) Some of the solid basalts weather with pimply excrescences. A good example may be examined below the Calgary road, at the foot of the cliff above the south end of the rocky foreshore, half a mile south of Lainne Sgeir. Here, solid pimply-weathering basalt may be seen passing laterally into vesicular basalt with conspicuous analcite crystals contained in druses. (2) An interbanding of slaggy and solid basalt within the limits of a single flow is exposed just on the margin of the map, south from Treshnish Point. (3) A few of the lavas carry contemporaneous pegmatitic segregations of felspar and idiomorphic augite that can be easily distinguished with the naked eye. These crystal growths form little felspathic patches or, in some cases, the outer lining of amygdales. Examples have been noted on the northern ridge of Beinn na Cille, about three quarters of a mile from the summit; others again occur in the amygdaloidal portion of a banded lava exposed in a gorge of Allt Mòr, due east of Calgary Castle. E.B.B.

ARDNAMURCHAN

Ben Hiant and Ardslignish.—Two outliers of basalt lavas occur east of Ben Hiant; the one forms part of the wall of the Ben Hiant vent, the other extends north-west from the Ardslignish peninsula almost to Loch Mudle. The two are separated by the Loch Mudle Fault, the displacement of which is roughly 250 ft. down to the north-east. The total thickness of lavas preserved in the Ben Hiant and Ardslignish outliers is only about 100 and 300 ft. respectively. In both outliers, the lavas are practically free from pneumatolytic and contact alteration, and they weather spheroidally with characteristic reddish-brown hues.

On the south and east sides of Ben Hiant, good lava exposures may be seen along escarpments, up to 100 ft. high. Each flow is often not more than about 12 ft. thick and consists of slag above and solid basalt below. On the north-east face of the hill, a dark cliff consists of lavas greatly brecciated as a result of the vent explosions.

In a stream half a mile directly south-east of Ben Hiant summit, the slag overlying the solid lower portion of the basal flow is banded. In a sense, each band represents a miniature lava-flow, 2 or 3 inches thick, with its base marked by a striking development of pipe amygdales, in contrast to small round vesicles that occur in its top. These pipe amygdales are inclined in one direction,[1] perhaps indicating flow of the basalt after a development of originally vertical pipes. The individual bands are clearly distinguishable and are interpreted as due to the repeated overflow of still-liquid lava on to a previously consolidated crust. This explanation has already been given for similar occurrences in Mull.[2]

Non-porphyritic olivine-basalt of coarse or medium grain is the common type of rock, but porphyritic basalt has been noted in the Ben Hiant district and elsewhere in Ardnamurchan at or near the base of the group. For example, the basal flow referred to in the preceding paragraph is porphyritic, with numerous felspar phenocrysts. A compact type occurs on the east face of Ben Hiant at the north end, and also on the north side of the hill, next to the Ben Hiant intrusion. In this case, no typical slag is seen, though some exposures are amygdaloidal. Under the microscope this rock is a microlithic olivine-basalt (21445). J.E.R.

The Ardslignish outlier, east of the Loch Mudle Fault, is crossed at the road north of Ardslignish by another fault. The throw is 200 ft. and brings the base of the lava series approximately down to sea-level in the peninsula. The outlier as a whole furnishes an excellent example of plateau-lava country. There are at least twenty flows preserved. All appear from their field-character to be olivine-rich basalts, or fine-grained dolerite, of Mull Plateau Types. Trap featuring is pronounced and shows a gentle dip which is usually a little to the north or south of west Escarpments exhibit a rude approach to a blocky columnar structure. Segregation veins have been noted at intervals along the west coast of Ardslignish, and pipe amygdales occur 500 yds. south-west of Beinn Bhuidhe summit, just beyond the limit of the Memoir-map. J.B.S.

An unusual feature is presented by the basal flow near the north end of the Ardslignish outlier at a point just east of the Loch Mudle Fault, half a mile south-east of Loch Mudle. There, just north of a stream-gully cut in the basal lava-escarpment, the lowest lava-flow is brecciated from top to base. The amygdaloidal upper portion is affected almost as much as the solid lower part of the flow. The brecciation, however, does not extend far laterally, for the basal lava in the adjoining stream-gully is quite sound throughout. The angular fragments are of various sizes and are separated by dark, compact material. Under the microscope, Dr. Thomas finds that this matrix consists of comminuted basalt and felspar, together with numerous grains of angular quartz (22438), and that the basalt itself is similar in type to the pillow-lavas of Central Mull[3] (22289, 22290). Possibly the lava flowed into a pool or lake, and by its sudden cooling became brecciated. Similar brecciation of lava-flows is commonly met with in the case of the Lower

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[1] Sir A. Geikie illustrates a similar case from Skye: 'Ancient Volcanoes of Great Britain,' vol. ii., 1897, p. 191.

[2] J. E. Richey *in* 'Tertiary Mull Memoir,' 1924, p. 114.

[3] 'Tertiary Mull Memoir,' 1924, Fig. 21, p. 151.

Old Red Sandstone lavas of the Lorne Plateau, of which the general subaqueous origin is beyond doubt.[1] It seems perhaps less likely that the brecciation of the Ardslignish lava was due to volcanic explosion, and that the material infilling the interstices is tuff. J.E.R.

Kilmory and Brachouse. An irregularly bounded set of lava outcrops roughly follows the course of the road from Camphouse, by Brachouse, north to Kilmory. The lavas are separated from the older rocks of the district by vent agglomerates, and are often so shattered that no two observers would agree as to where broken lava ends and vent agglomerate begins. It is quite possible that the lavas as a whole have dropped down to some extent with reference to the older rocks that lie to the south and east. Though probably as much as 1000 ft. of these lavas are exposed, there is no trace of trap featuring, and it is impossible to follow details of structure. There can, however, be no doubt of the identification of the lavas, for they repeatedly show characteristic passages from solid into slag.

Most of the exposures suggest commonplace Plateau Basalt Types. The following exceptions may be noted. Basalt with big felspar phenocrysts occurs in the point north of Kilmory. Mugearite has been noted 500 yds. east of the hamlet of Branault, a third of a mile south south east of Kilmory. Basalts with small felspar phenocrysts are common towards the southern extremity of the Brachouse outcrop. For instance, a small quarry has been opened in basalt of this type by the main road west of Loch Mudle, 150 yds. east from its junction with the Brachouse road.

Everywhere olivine has been decomposed, presumably by the gases that issued from the volcanic vents. E.B.B., J.E.R.

Kilchoan. Various isolated outcrops of the basalt lavas occur in this district, the most extensive of which forms the Glebe Hill, north west of Kilchoan. They are all altered to a greater or less degree, and no fresh olivine is found. Where they border the Ring-dyke Complex they become highly granulitized. Near Kilchoan the lavas are in fault contact with Mesozoic sediments and Moine Schists, but their base is well exposed beyond the west side of Kilchoan Bay, in sea cliffs forming the headland of Sròn Bheag.

The lavas on the Glebe Hill are greatly baked by the adjoining Ring dyke Complex, and appear to form a capping to the outermost intrusion (Hypersthene gabbro). They apparently are near to the base of the lava group (p. 104). Along the summit, porphyritic basalt forms a considerable outcrop, and though there are no associated slags, the rocks are presumably extrusive.

Less altered amygdaloidal lavas are exposed alongside the main coast-road, south west and south east of the Established Church Manse. Two successive lava flows may be seen at low tide between the mainland and the island of Glas Eilean, on the east side of Kilchoan Bay, where the lavas are dipping to the west (Fig. 13,

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[1] E. B. Bailey *in* 'The Pre-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1925, pp. 23, 24.

p. 132). Epidote often occurs in this vicinity as greenish streaks and in vesicles, and was perhaps formed by vapours emanating from the adjacent Glas Eilean Vent.

Basalt Lavas involved in the Ring-dyke Complex.—These outcrops are considered under a separate heading, since they are so completely isolated from all others.

On the south-west side of Meall an Tarmachain, basalt and agglomerate form a complicated highly baked mass of considerable size, which serves partly as capping and partly as wall to gabbro-intrusions. The basalt, which is frequently amygdaloidal and certainly lava, is fine-textured, dark in colour, and in many places brecciated. Smaller outcrops of compact basalt associated with agglomerate have been mapped to the south of this large mass.

Another mass of compact basalt is shown much farther within the Ring-dyke Complex, between Beinn na Seilg and Aodann. It also is associated with agglomerate, which contains fragments of a similar basalt. The baking of these rocks is so intense that amygdaloidal structure is detected with difficulty. On fractured surfaces, amygdales can be made out in outline, but they are mere ghosts. On exposure to weather, however, they sometimes stand up fairly prominently, and their diagnosis is then easier.

Still more intense alteration is met with on Meall nan Con, and equally affects the basalt lavas and vent-materials (agglomerate and tuff) there mapped. Indeed, so highly granulitized are these rocks that it is often impossible to make out any original structure in the hand-specimen, and the boundary line on the Memoir-map is only approximate. Under the microscope, however, the fragmental nature of the vent-materials is apparent, while even-textured granulites are probably basalt lavas. J.E.R.

PETROLOGY

North-west Mull.—The plateau types of basalt as represented in this district have received full attention in the Memoir descriptive of the Tertiary rocks of Mull, and the reader is referred there for a detailed account of their petrography.[1] It was there pointed out that microporphyritic olivine-basalts, characterized by titaniferous augite with ophitic to hypidiomorphic granular structures, were representative of the greater proportion of the lava-flows, more especially of those of the earlier part of the lava-sequence.

Ardnamurchan.—As has been indicated in the foregoing account of their distribution, the plateau lavas do not occupy very extensive tracts of country but are mainly encountered in relatively small isolated areas. They may occur either as outliers of the main basalt plateau, may be preserved in the volcanic vents, or may exist as integral parts of screens bounded by plutonic rocks of later date. In the vents and screens the lavas have been, to a considerable extent, robbed of their original characters and have suffered thermal and other alteration of varying degree. These altered and metamorphosed lavas will, for the most part, be referred to later under the heading of the rocks with which they are associated or those to which their metamorphosed condition is due. In the present instance we shall confine ourselves chiefly to a description of the rocks in their normal state.

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[1] H. H. Thomas and E. B. Bailey in 'Tertiary Mull Memoir,' 1924, p. 136 *et seq.*

The two main areas of unaltered plateau lavas lie respectively to the south-east of Ben Hiant (22435–7) and in the outlier of Ardslignish (24462–4), the latter marking the most easterly occurrence of such lavas on the north side of Loch Sunart.

These lavas are dark-grey to black microporphyritic rocks which may for the most part be described as normal olivine-rich basalts, and which are comparable in every respect with those of the plateau region of Mull.[1] Their texture is moderately coarse but naturally varies somewhat in accordance with the thickness of individual flows. Structurally they are microporphyritic with dominant olivine and quite subordinate felspar (22436) as the porphyritic constituents. As in the plateau basalts beyond the pneumatolytic limit of Central Mull, the olivine of these rocks is mainly in a fresh condition, and it is only on occasions that it is partially serpentinized or pseudomorphed by carbonates. The augite is characteristically titaniferous, it exhibits the lavender tint generally associated with such a composition, and occurs in ophitic relationship to the lath-shaped crystals of labradorite. The felspar laths, usually twinned and zoned, form an interlacing network that encloses granules of olivine, granular augite, moderately abundant crystals and patches of titanomagnetite and a variable amount of residual base. The original character of the ultimate product of consolidation is frequently masked by more or less complete analcitization and zeolitization, which give rise to patches of turbid analcite, radial growths of natrolite, and other zeolites. Frequently the analcitization extends to the felspar (22435), and may completely obliterate all original characters other than external form. It is this type of plateau basalt which in the thicker flows shows a tendency to segregate contemporaneously certain of its constituents into ill-defined veins of coarser texture. These segregations consist mainly of titaniferous augite and zoned basic plagioclase in a distinctly alkaline residuum composed of alkali-felspar and analcite. In such veins the augite crystals are usually idiomorphic and frequently exhibit hour-glass structure. Moreover they often demonstrate the introduction of the aegirine molecule by presenting a green peripheral layer of aegirine-augite to the alkaline matrix in which they are embedded. As pointed out in the case of similar occurrences in Mull[2] these veins are of special interest, as they afford evidence of the segregation of a rock of definitely alkaline affinities from a magma of plateau basalt composition.

Although the microporphyritic types are by far the more prevalent, non-porphyritic types are occasionally encountered and amongst these we may mention a micro-ophitic type that quite commonly occurs in the Mull sequence. It is a type that exhibits a mottled structure due to elliptical or rounded patches of augite ophitically enclosing felspar and separated from each other by a matrix of felspar laths, granular olivine, and magnetite. It is a feature of these rocks that olivine, instead of being evenly distributed, is frequently concentrated in the interspaces beyond the limits of the ophitic augite. This presumably points to a late crystallization of olivine or, conversely, to an early separation of augite. A flow of this type occurs to the north of Ardslignish farm (24464), in association with the normal microporphyritic types of plateau basalts.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 136, *et seq.*

[2] *Ibid.*, p. 138.

Another type associated with the normal plateau basalts of Ardslignish is a compact basalt (24465) with microporphyritic labradorite in a matrix of small irregular crystals of labradorite-andesine, hypidiomorphic granular augite, magnetite, apatite, and a small amount of devitrified and altered residual glass. The presence of felspar as the only phenocrysts, the hypidiomorphic granular structure of the matrix, and the sparsity of olivine, are features commonly exemplified by lavas of the Central Type as developed in Mull.

An interesting lava that shows signs of brecciation forms the lowest member of the Ardslignish outcrop (22289–90). It is much decomposed but it can be recognized as a highly vesicular olivine-basalt. Olivine, as microporphyritic individuals, is represented by calcite pseudomorphs. The bulk of the rock, however, is composed of irregularly terminated small laths and skeletal crystals of plagioclase set in a dark basic residuum that has solidified with a micro-variolitic structure. This basic residuum has invariably invaded the abundantly occurring vesicular cavities, giving these a continuous lining of varying thickness. The ultimate infilling of the vesicles belongs to a later period and is composed of calcite and secondary silica. The rock presents characters that suggest more rapid chilling than that usually met with in lavas of this type. The lining of the vesicles by glassy residual matter and the sub-variolitic crystallization of the base recall in some measure structures presented by the rapidly chilled pillow lavas of Mull.[1]

In the lavas preserved in the neighbourhood of Camphouse we have a group of flows, in part at any rate, referable to the plateau types of olivine-basalt, but of a somewhat finer texture. Although great alteration of the nature of serpentinization, chloritization, and albitization, has affected their original constituents, the survival of their original structures enables their types to be determined. An olivine-rich type is present (22693), while more compact rocks less rich in olivine are also represented (26090). The changes these rocks have suffered are similar to those which affected the plateau basalts of Central Mull within the pneumatolytic limit of that region. A compact olivine-free type (22691) has amygdales that are composed of yellow garnet, pale-green actinolite, yellow epidote, calcite, and what appears to be chabazite. The garnet and epidote are peripheral while the zeolite occupies a more central position. The garnet occurs as small grains that occasionally have idiomorphic outlines, the epidote as small prisms, and the actinolite as needles and fibrous patches. The zeolite furnishes rhomboidal and trigonal sections, and has the low birefringence and refractive index of chabazite. This mineral assemblage recalls that met with in the pneumatolysed and metamorphosed lavas of An Gearna in Mull, which were made the subject of special study by Dr. McLintock.[1] H.H.T.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 150, 151.

Folding and Faulting, Ardnamurchan

It seems convenient to describe in the present chapter the main folds and faults of Ardnamurchan, although many of the faults and crush-lines affect not only the bedded rocks heretofore dealt with, but also the succeeding intrusive rocks such as the ring-dykes. These structures are chiefly demonstrated with reference to the Mesozoic strata, as being more extensively developed than the Tertiary basalt lavas, but are for the most part, if not altogether, of post-basalt-lava date.

Away from the vicinity of the plutonic complex, in the more easterly parts of the area, the Mesozoic strata and Tertiary basalt lavas are horizontal or gently inclined in various directions. Around the plutonic complex, however, the Mesozoics are everywhere tilted at angles of about 30 degrees outwards from the plutonic masses. As will be seen on Pl. II, p. 71, the dips are for the most part directed away from Centre 2, as though the dome which they indicate had been developed in relation to this centre. The Mesozoic outcrops are discontinuous, but the dome-structure is sufficiently demonstrable from the vicinity of Kilchoan westwards around the nose of the peninsula almost to Ardnamurchan Point, that is, around a quarter of a circle about Centre 2. On the northern coast, west of Faskadale Bay, where the Mesozoics are once more exposed, the dome-structure is again evident, though here the strata appear to be inclined away from Centre 3, rather than from Centre 2.

From the evidence west of Kilchoan it would seem that the doming is not only earlier than the ring-dyke intrusions of Centre 2, but must have been effected prior to the injection of the Outer Cone-sheets belonging to this centre, which preceded the ring-dykes in time. In the first place, the contact-surface of the outermost ring-dyke of Centre 2 (the Hypersthene-gabbro) with the domed Mesozoics westwards of Kilchoan is much steeper than the dip of the Mesozoics; though inclined in the same direction. The transgressive gabbro-junction thus indicated is perhaps most marked immediately to the north-west of An Acarseid, 3 miles west of the head of Kilchoan Bay. At this point the contact-surface of the gabbro is practically vertical against the tilted Mesozoic shales and Tertiary basalt lavas (*see* p. 220 and Fig. 27, p. 205). Further, on the hill slopes west of Kilchoan Bay, the cone-sheets cutting the domed Mesozoics are inclined towards Centre 2 at no less an angle than others farther to the east outside the limits of the dome. If the doming were later than the injection of the cone-sheets, an original inclination of, say, 40 degrees for the cone-sheets should be no more than 10 degrees within the area of the dome.

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[1] W. F. P. McLintock, 'On the Zeolites and Associated Minerals from the Tertiary Lavas around Ben More, Mull,' *Trans. Roy. Soc. Edinburgh*, vol. li., 1915, p. 4.

As suggested in Chap. XIV, p. 178, the doming may be due to an increase of pressure in the magma-reservoir, which subsequently found relief in the intrusion of the Outer Cone-sheets. A detailed study of the domed rocks west of Kilchoan Bay shows, however, that the structure is by no means a simple one, but is complicated by faults (proved by mapping) and reversals of dip. It is noticeable that variations in the prevalent dip are most marked in the neighbourhood of the faults, as though due to fault-movement. For example, in the vicinity of the north-east fault that brings down basalt lavas and underlying fine-grained white sandstone against Lower Lias shales, a mile south-east of Beinn na Seilg, the dip of the Lower Lias shales changes from the normal 25–30 degrees to 10–15 degrees (*see* Fig. 28, p. 219), while close to or at the fault itself the dip becomes reversed in direction and is very steep.

The fault-planes are never well seen, partly owing to lack of exposure, partly on account of the subsequent metamorphism of the rocks by the ring-dykes. Consequently, the relations between the faulting and the Outer Cone-sheets have not been determined by means of actual contacts. Sometimes, however, as in the case of the important east-west fault that crosses the Sròn Bheag headland, it is fairly evident in the field that the cone-sheets continue without interruption across the line of fault (*see* Fig. 3, p. 34).

The fault last mentioned, just before it reaches the coast to the west, crosses a hollow eroded along a later north-south crush-line. On the rock-face bounding the hollow to the west, Lower Lias shale overrides Middle Lias sandstone, so that this fault is evidently reversed. Owing to the intense baking of the rocks the position of the actual fault-plane is difficult to determine to within a few inches.

Outside the area of doming, eastwards of Kilchoan, the Mesozoic rocks form a fringe along the south coast as far east as the mouth of the river that flows past Camphouse. A short distance east of this point, the base of the Mesozoics (Trias on Moine Schists) rises abruptly, for it is met with at a height of about 300 ft. above sea-level on the west side of Ben Hiant. Around the south-eastern slopes of this mountain it extends up to higher and higher levels till, on the east face, it approaches the 800-foot contour. This rise of the Mesozoic base eastwards in Ardnamurchan was first noted by Sir Archibald Geikie,[1] and is to be correlated with a similar rise demonstrated by Prof. Judd[1] in Morven, south of Loch Sunart. It is not at present known whether the tilting of the Mesozoic floor is earlier or later than the Tertiary basalt lavas. Possibly, when Morven is mapped in detail, evidence of an easterly overlap of the lavas against a rising floor of the Mesozoic rocks may be obtained, indicating a pre-Tertiary date for the uplift. However this may be, it is certain that there is post-lava faulting on the Ardnamurchan side of Loch Sunart. For example, the Loch Mudle Fault extends north-north-west across the Ardnamurchan peninsula from a point east of Ben Hiant, and downthrows the lava-base to the north-north-east about 250 ft. (*see* p. 110). The fault also shifts the outcrops of cone-sheets and a tongue-like extension of the Ben Hiant Intrusion, which lie south-east of Loch Mudle, and is certainly a late structure.

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[1] Sir A. Geikie, 'The Ancient Volcanoes of Great Britain,' vol. ii., 1897, pp. 279–280, footnote.

Numbers of similarly late faults and lines of crush traverse the Ardnamurchan district, and affect all the intrusive rocks, including the latest of the ring-dykes. The majority are simply lines of crush unaccompanied by any appreciable movement. Some are demonstrably tear-faults, and shift laterally the outcrops of the ring-dykes. As examples may be cited the two crush-lines that extend approximately north and south to the west of Beinn na Seilg and effect lateral displacement, not only of ring-dyke margins, but also of the Inner Cone-sheets of Centre 2.

The faults and crush-lines of late date vary in direction from north-west to east of north. The majority, however, would appear to be directed north-north-west. Though only those that shift outcrops are shown on the Memoir-map, the presence of many others is indicated by the north-westerly and north-north-westerly direction of much of the river system of Ardnamurchan. Many more have left their impress on the scenery in numerous straight-running hollows crossing hillsides. Crush-lines have indeed considerably affected the landscape in Ardnamurchan as in other Tertiary igneous districts of Britain. J.E.R.

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[1] J. W. Judd, 'The Secondary Rocks of Scotland. Third Paper. The Strata of the Western Coast and Islands,' *Quart. Journ. Geol. Soc.*, vol. xxxiv., 1878, Pl. xxxi., p. 660.

CHAPTER XI

TERTIARY VOLCANIC VENTS, CENTRES 1 AND 2, ARDNAMURCHAN

EXTENSIVE volcanic vents, mainly filled with agglomerate, are met with in the eastern part of the Ardnamurchan igneous complex. They pierce Tertiary basalt lavas, Mesozoic sediments and Highland schists, but are traversed by cone-sheets belonging to Centres 1 and *2*, and are therefore of comparatively early date. Though they are demonstrably later than only an inconsiderable thickness of basalt lavas with which they are actually in contact, there is little room for doubt that they belong to a later period than the widespread Plateau Group of the adjoining parts of Mull and Morven. In the first place, the vent materials of volcanic origin differ markedly in composition from these basic lavas. The agglomerates are largely composed of fragments of trachyte and more acid rocks, together with blocks of big felspar basalt, while pitchstone lavas are associated with the vents of the Ben Hiant district. Further, no intercalation of such materials is known from the lava-succession of Morven and Northern Mull. It is true that in the upper part of the Plateau Group in Central Mull intercalated flows of big felspar basalt have been noted. But the long duration of the pre-cone-sheet vent period in Ardnamurchan, during which no typical plateau basalt is known to have been erupted, seems to indicate its distinctness from the period of the plateau lavas. On Ben Hiant, for example, two successive vents have been mapped in which agglomerates are interleaved with recurring beds of tuff, and also, in the case of the more southerly vent, with a few flows of pitchstone lava. The infilling of these two enormous cavities must therefore have extended over a considerable time.

The vents earlier than cone-sheets may be subdivided into two groups, the Ben Hiant Vents and the Northern Vents (*see* Pl. II, p. 71). The Northern Vents terminate westwards against later plutonic intrusions—the Ring-dykes of Centre 3—but originally they probably extended over much of the area now occupied by these ring-dykes, for agglomerates of like composition to those of the Northern Vents are preserved as screens and cappings within the plutonic complex, and are found even as far west as Aodann within the Ring-dyke Complex of Centre 2. In addition to these early vents there is a small linear vent at Glas Eilean south of Kilchoan, which is later than the Outer Cone-sheets of Centre 2, and is referred to this intrusion-centre.

The explosive character of acid magma has been well exemplified in the repeated volcanic outbreaks of Central Mull,[1] and is also manifested in all the Ardnamurchan vents. It may be noted that at a later period certain of the basic ring-dykes of Ardnamurchan were completely or partially brecciated and then granulitized or recemented by granophyre, and that the brecciation is to be attributed to explosive gases derived from the granophyre magma.

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[1] E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 202, 203.

Vent-walls are clearly exposed in the case of the Ben Hiant Vents. On the other hand, country rocks bounding the agglomerates of the Northern Vents are often much brecciated, and the exact position of the vent-walls is in such places difficult to determine. Marginal brecciation is most in evidence at interior contacts of the vent-agglomerate with basalt lavas, and it is clear that the shattered basalt lavas are earlier than the agglomerates. It is likely that these interior masses of basalt lava have slipped down into the vents. Brecciated country rocks of all kinds also form a large proportion of the materials of the agglomerates. In the Ben Hiant agglomerates, on the other hand, fragments of country rocks are little in evidence, and basalt lava only has been noted.

It will be seen on Pl. II, p. 71, that the outcrops of agglomerate infilling the Northern Vents are elongate and often arc-shaped. The outer, eastern, vent-wall curves in a clock-wise direction from the northern coast till terminated to the south by the Ring-dyke Complex of Centre 3. This wall extends over one third of the circumference of a circle, the centre of which lies about a mile within the eastern edge of the ring-dyke complex just mentioned. The circle, if completed, would include within it the isolated patches of agglomerate involved in the ring-dyke complexes to the west, and also the outcrops along the northern coast north of the ring-dykes. Cone-sheets and early major intrusions associated with, though later than, the Northern Vents also curve around in parallelism with the outer wall of these vents. There is, therefore, little doubt that an early centre (Centre 1), about which vents and intrusions are grouped, was situated in the eastern part of the Ardnamurchan Complex.

The Ben Hiant Vents lie to the south-east of the outer bounding wall of the Northern Vents, but there is reason for connecting both vent-complexes with the same igneous centre. Both belong to the same period in the igneous cycle, and in both the contained volcanic materials are similar. Further, the two Ben Hiant Vents lie along a north-east line as if referable to Centre 1.

BEN HIANT VENTS

(EARLIER THAN CONE-SHEETS)

Ben Hiant, the highest peak in western Ardnamurchan, has long been known to geologists from the writings of Prof. J. W. Judd and Sir Archibald Geikie. Judd's publications date from 1874 to 1890,[1] Geikie's results are given most fully in his 'Ancient Volcanoes of Great Britain.'[1] Striking features of this hill are its magnificent cliff-sections of agglomerate and a great central mass of dolerite (the Ben Hiant Intrusion). With regard to these two rock-bodies, Judd and Geikie arrived at divergent conclusions. Judd interpreted the central dolerite mass, in part at least, as a pile of lava-flows, and the agglomerates as underlying them and resting transgressively across the denuded edges of the plateau basalts and older stratified rocks. Geikie rightly contended that the dolerite was intrusive, and pointed out that the outcrops of agglomerate were in some cases clearly seen to lie within vent-walls. His conclusions are in the main confirmed by the recent detailed survey. No more than two large vents can, however, be determined, whereas Geikie has indicated in his illustrations a number of small vents. The outcrops of agglomerate which he investigated are separated from one another by the later, intrusive dolerite, and they probably all form part of one large vent, here termed the South-west Vent. The second vent indicated by the recent mapping lies north-east of, and in contact with, the South-west Vent, and is called the North-east Vent.

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[1] J. W. Judd, 'The Secondary Rocks of Scotland. Second Paper. On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata,' *Quart. Journ. Geol. Soc.*, vol. xxx., 1874, pp. 261–264; and 'The Propylites of the Western Isles of Scotland,' *Quart. Journ. Geol. Soc.*, vol. xlvi., 1890, pp. 373–380.

With regard to the dolerite, although its scarp-featuring suggests that it is built up of sheets, as both Geikie and Judd concluded, a close examination fails to locate any sheet-junctions where these are to be expected. The featuring is here considered to be due to weathering along various planes of weakness (*see* pp. 160–1). Judd's misinterpretation of the dolerite as a pile of lavas appears to be mainly due to his having overstressed certain petrographical evidence. He had knowledge of a glassy rock (pitchstone) on Ben Hiant, which he has included with the dolerite on his map.[2] As we now know, the pitchstone is associated with the agglomerates, not with the dolerite. It occurs in sheets, which are interpreted as lava-flows within the South-west Vent. Judd also considered the pitchstone to be lava, comparing it with the pitchstone lava of the Sgùrr of Eigg,[3] but thought that he recognized a significant petrographical resemblance between it and the dolerite, because the latter usually has a sub-vitreous (variolitic) ground-mass. Nevertheless, though the essentially intrusive nature of the Ben Hiant Dolerite must be maintained, there is evidence that the mass may have consolidated under little cover (*see* p. 168).

As already mentioned, the agglomerates of Ben Hiant are interstratified with beds of ash and the pitchstone lavas. In the South-west Vent they are contained within high vent-walls. Further, fragments of country rock are, with the exception of one mass, only found in the agglomerates in the immediate vicinity of a vent wall. It is therefore concluded that this vent possessed an open crater, the walls of which cannot have been less than 1100 ft. high, the greatest height above sea-level at which the bedded vent-materials are now on view.

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[1] Sir A. Geikie, 'The Ancient Volcanoes of Great Britain,' vol. ii., 1897 pp. 278–280, and pp. 318–322.

[2] J. W. Judd, *op. cit.*, 1890, Fig. 1, p. 374.

[3] J. W. Judd, *op. cit.*, p. 376.

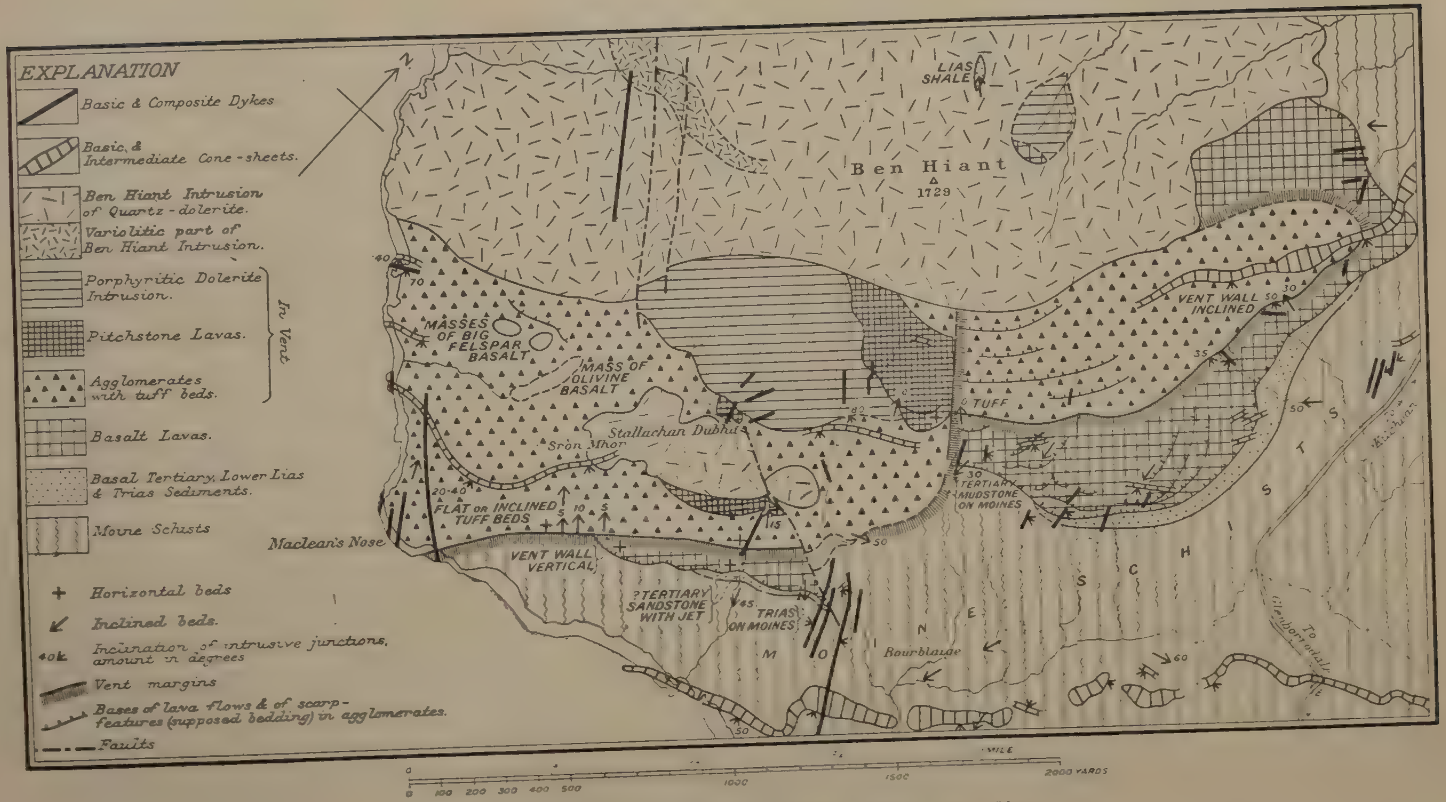

EXPLANATION
Basic & Composite Dykes
Basic & Intermediate Cone-sheets.
Ben Hiant Intrusion of Quartz-dolerite.
Variolitic part of Ben Hiant Intrusion.
Porphyritic Dolerite Intrusion.
Pitchstone Lavas.
Agglomerates with tuff beds.
In Vent
Basalt Lavas.
Basal Tertiary, Lower Lias & Trias Sediments.
Moine Schists
Horizontal beds
Inclined beds.
Inclination of intrusive junctions, amount in degrees
Vent margins
Bases of lava flows & of scarp-features (supposed bedding) in agglomerates.
Faults
N
Ben Hiant
1729
LIAS SHALE
VENT WALL INCLINED
TUFF
MASSES OF BIG FELSPAR BASALT
MASS OF OLIVINE BASALT
Stallachan Dubha
Sròn Mhor
FLAT OR INCLINED TUFF BEDS
20-40
Maclean's Nose
VENT WALL VERTICAL
?TERTIARY SANDSTONE WITH JET
TRIAS ON MOINES
TERTIARY MUDSTONE ON MOINES
MOINE SCHISTS
Bourblaige
To Glenborrodale
Kilchoan
0
100
200
300
400
500
1000
1500
2000 YARDS
MILE

FIG. 10.—*Map of Vent-Complex, eastern side of Ben Hiant.*

Walls of North-east Vent.—The north-eastern agglomerates, which for reasons stated below are concluded to lie within an older vent, have well-exposed contacts with vent-walls of basalt lava. The contacts are seen alongside two streams on the steep eastern face of Ben Hiant, overlooking the Kilchoan–Glenborrodale road, and are inclined downwards towards the interior of the vent at angles of 35 and 50 degrees respectively. In the more southerly stream it is of interest that a composite dyke cutting the lavas is truncated by the vent-margin (Fig. 11), demonstrating that an intrusive episode intervened between the basalt lavas and the volcanic agglomerates concerned. The agglomerates form a cliff rising from the inclined crater-wall, and in them a parting of tuff similarly inclined is seen at one point. A parallel arrangement of the blocks in the agglomerates is also noticeable in places, which may be due to the slipping of such fragments down the interior slope of the volcano.

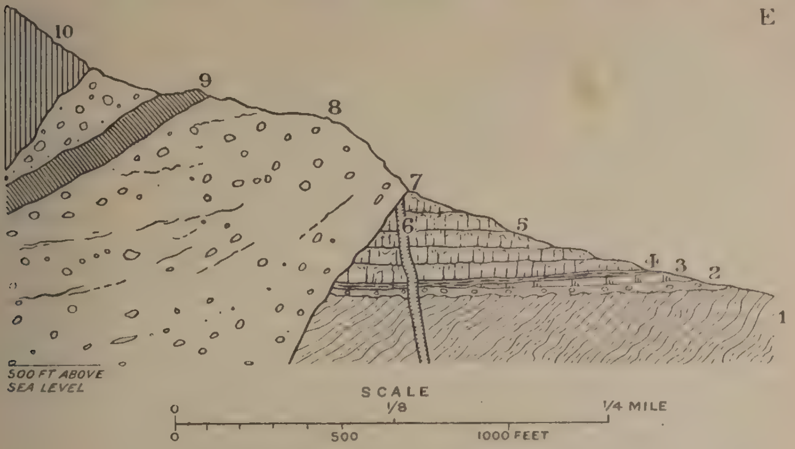


FIG. 11.—*Section of North-east Vent of Ben Hiant.*

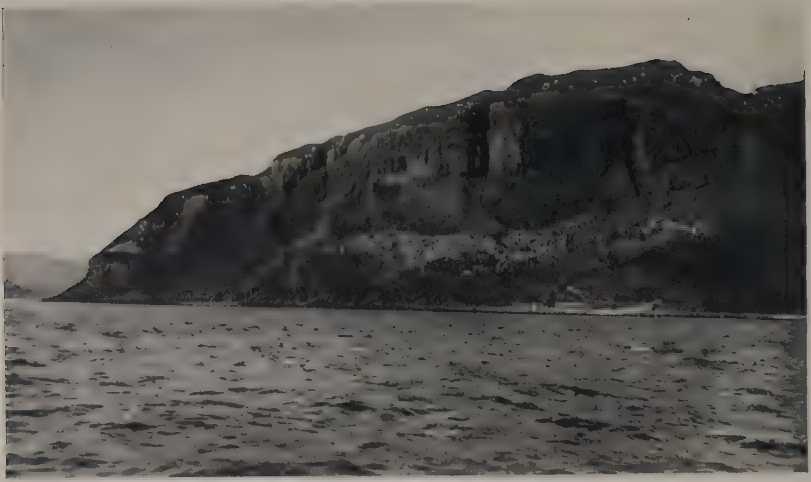
1, *Moine Schists.* 2, *Trias.* 3, *Lower Lias limestone.* 4, *Basal Tertiary mudstone.* 5, *Tertiary basalt lavas.* 6, *Pre-vent composite dyke.* 7, *Edge of vent.* 8, *Vent-agglomerate.* 9, *Quartz-dolerite cone-sheet.* 10, *Ben Hiant Intrusion of quartz-dolerite.*

To the north, the agglomerates are bounded by basalt lavas that are exposed in a prominent cliff overlooking lower ground floored by the Moine Schists (Fig. 19, p. 160). The lavas are much brecciated, and it is a matter of opinion where to draw a boundary between this broken material and vent breccias and agglomerates. No extraneous volcanic material is found among the broken basalt of the cliff, and the actual edge of the vent is therefore concluded to lie to the south of the cliff, as shown on the Memoir-map. Such intense brecciation is an unusual feature of the walls of the Ben Hiant Vents.

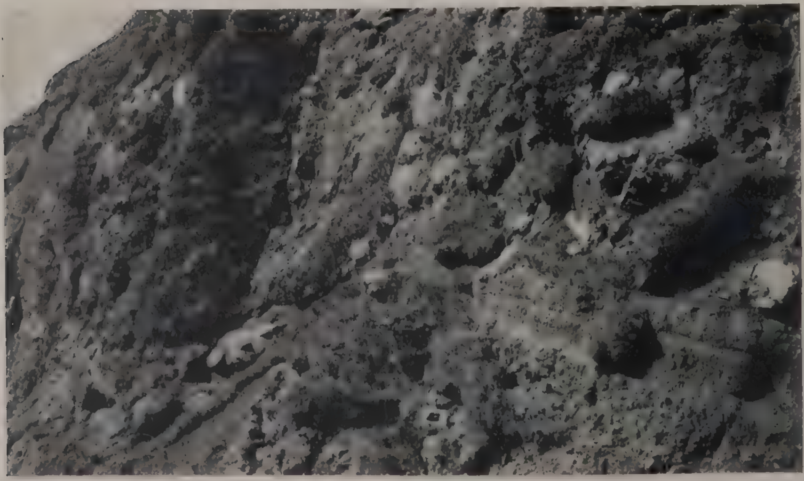
Walls of South-west Vent.—It will be seen in Fig. 10 that this vent is bounded to the south-east by older rocks, the junction with which extends from sea-level on the east side of Maclean's Nose for a mile to the north-east. In the vicinity of this headland it can be demonstrated that the junction is steep or vertical. On the shore immediately east of the headland agglomerates are in contact with Moine Schists, while a quarter of a mile to the north-east, at a height of about 500 ft., they abut against a vertical wall of horizontally bedded basalt lavas. In the intervening ground the agglomerates form high cliffs, which may be pictured as the cast of the crater, of which the wall has been eroded away (Pl. III). North-eastwards from the vertical contact just mentioned the exposed edge of the vent keeps to one level without change in direction for a quarter of a mile. The various junctions seen are described in detail below.

East of Maclean's Nose, close to high-water mark, the agglomerates are in contact with reddish felspathic Moine Schists. Landslipping has occurred in this vicinity, but there is evidence that the rock-mass showing this contact is undisturbed. It is traversed by a north-west dyke and by a north and south line of crush, both of which are in line with a corresponding dyke and line of crush in the adjoining cliffs of agglomerate. It seems unlikely that landslipping could have taken place without altering the orientation of the dyke and crush-line. The vertical junction of agglomerate with the basalt lavas is seen at the top of grassy scree-covered slopes, in an angle of the cliffs where a projecting buttress of flatly bedded basalt lavas ends against still higher cliffs of agglomerate. The junction is sharp and clean-cut, and the reddish-brown spheroidally-weathering lavas bordering it are easily distinguished from the agglomerate in contact, which is fine-textured and greyish in colour. Farther north-east the edge of the vent is again exposed in two stream-sections. In the sides of a steep gully formed by the first stream, agglomerate and flatly bedded tuff abut against a steep wall of basalt lava. The actual junction, however, is disturbed, as though the vent-materials had slipped down at their contact with the vent-wall. In the second stream, beyond a fault against which the lavas terminate, a small mass of intrusive dolerite of Ben Hiant type is interposed between agglomerate and Moine Schists.

North-east of the last-mentioned stream the vent-margin bends somewhat abruptly, runs uphill to the north-west, and forms a north-eastern boundary to the South-west Vent. Along this margin a vertical junction of fine-grained agglomerate with basalt lava is exposed just south-west of where another stream has cut a channel in the lava-escarpment. It will be seen from Fig. 10 that this line, continued farther to the north-west, exactly separates two sheets of pitchstone lava belonging to the South-west Vent from agglomerates that occur to the north-east, and which are included with the North-east Vent. The agglomerates are evidently bedded, as shown by an interbedded tuff seen in the stream, and by their scarp-features that run at right angles to the line of junction with the pitchstone lavas. The conclusions are drawn that the agglomerates to the north-east are bedded in an older vent, that a later



A.—*View of Maclean's Nose, Ardnamurchan, from east.*
(For Explanation, *see* p. viii.)



B.—*Agglomerate cliffs of Maclean's Nose.*
(For Explanation, *see* p. viii.)

vent was formed to the south-west, and that the pitchstone lavas extruded within it terminated abruptly against a wall composed of the earlier bedded agglomerates. The stream above mentioned bends near its source across the junction of the earlier agglomerates and the upper of the two pitchstone lavas. Exposures of these rocks occur within a foot or two of one another, but their actual contact is not seen. The pitchstone is, however, unbrecciated, and is with little doubt later than the adjacent agglomerates. There is further evidence that the north-west line above described is not a line of fault. For, the inclined edge of the Ben Hiant Intrusion, that is later than all vent-materials but is traversed by many north-west crush-lines, crosses the line concerned at a right angle a short way uphill from the pitchstone lavas, and is neither shifted nor crushed at this particular point.

Since the Ben Hiant Intrusion separates the outcrops of vent-agglomerate on the north side of the hill, both from each other, and from the large outcrop to the south-west the walls of which have just been described, it cannot be definitely decided whether all these agglomerates lie within one vent or in several. The disposition of the outcrops would seem to suggest that they all belong to one vent (*see* Memoir-map).

No actual contact is seen between agglomerate and wall on the north side. In the steep banks of a stream south-east of Beinn na h'Urchrach, agglomerate outcrops a few yards from a bounding wall of Lower Lias limestone, and marmorization of the limestone was noted by Sir A. Geikie.[1]

MATERIALS INFILLING THE BEN HIANT VENTS

Agglomerates.—The agglomerates consist of angular fragments varying from a foot or more in length down to small particles, together with bombs of large size. These constituents seldom show any signs of bedding, though their stratified nature is evident since the agglomerates are interleaved with beds of tuff. Angular blocks of trachyte are perhaps most plentiful, but others of rhyolite and dacite are also usually present. All these rock-types may be found at any level in the 1000 ft. of agglomerate exposed in the South-west Vent, though it is often noticeable that at any particular place one type greatly preponderates over the others.

Vesicular structure is especially well developed in the darker, trachytic types. The vesicles do not show any concentric arrangement, and whether the fragments are shattered portions of bombs, or of lava-flows within the crater, is not certain. The vesicles are unfilled by amygdale-minerals, and the fragments would appear to have been broken off from their parent masses soon after solidification and before such minerals of late formation had time to crystallize. In contrast to the relatively small fragments of the more acid rocks, there are large sub-rounded blocks of big-felspar basalt (Fig. 12). These are especially numerous in the South-west

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[1] Sir A. Geikie, *op. cit.*, p. 280, footnote.

Vent, but have also been found in the uppermost layer of the earlier North-east Vent. The blocks are usually 6 ft. and upwards in length, and are interspersed amongst the more acid materials in the agglomerates. They do not bear vesicles, but have all the appearance of being true bombs. Two blocks of exceptionally large size, 50 to 80 yds. long, occur near the top of the western, seaward slope of Ben Hiant (*see* Fig. 10 and Pl. I, B). At their edges they are brecciated and veined by tuff, an observation made by Mr. Bailey. Perhaps these two immense masses are portions of a lava-flow within the vent, which became separated by subsequent explosions, though it is possible that they may be bombs.

Fragments of country rocks are absent or at any rate very rare in the Ben Hiant vents, except in the immediate vicinity of a vent-wall. For example, fragments of amygdaloidal basalt lava are abundant in the North-east Vent on its eastern side next to the inclined wall formed of these lavas. Again, at Maclean's Nose, amygdaloidal basalt fragments are restricted to the proximity of the vent-wall, here composed of Moine Schists. Since the basalt lavas occur in place at a height of some hundreds of feet above the latter locality, these fragments must have fallen down thus far at least into the vent. Blocks of schist have nowhere been noted, though angular quartz, which is plentiful in some of the tuff-beds, may have been derived from the comminution of schists by explosion (p. 136).

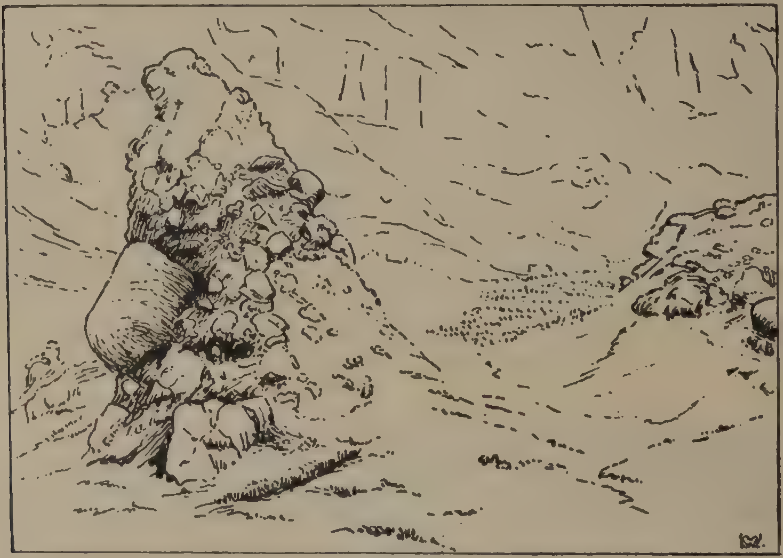

FIG. 12.—*Vent-agglomerate with large blocks of big-felspar basalt, near Maclean's Nose, Ben Hiant.*

Drawn from Geological Survey Photograph No. C. 2843.

An exception to the above rule is an elongate mass of brecciated olivine-basalt (21447), which lies far within the South-west Vent

(Fig. 10). Possibly it may be a remnant of a wall isolated by the subsequent enlargement of the vent, as in the case of the Kilchrist Vent of Skye.[1] The Ben Hiant Vents, however, differ from the Kilchrist Vent in the interbedding of tuff and pitchstone lavas with their agglomerates. Their orifices must consequently have been cleared of broken country rock by explosion, and open craters formed in which the vent-materials were laid down. Our information, however, is incomplete, in so far as no crater-floor is seen at the present level of denudation.

Bedded Tuff.—The various larger fragments in the agglomerates are, as a rule, bound together by others of smaller dimensions. Sometimes they are set in a matrix of fine ash or tuff. The deposition of the tuff often continued after the showers of larger fragments had ceased, so forming a distinct bed of tuff. Sometimes the upper surface of such a bed is well defined, with agglomerate abruptly overlying it (Pl. III, B). In other cases, the tuff grades upwards to form the matrix of the succeeding agglomerate.

Tuff-beds are well seen along the cliffs south-east of Maclean's Nose, where certain of them are indicated on Fig. 10 by bedding-signs. They are either horizontal or else very gently inclined towards the interior of the vent. They are usually only a foot or two in thickness, but range up to 5 ft. or more in some cases. Along the lower part of the cliffs above the talus slopes they were judged to recur at intervals of about 20 feet in the agglomerates. Owing to the steepness of the cliffs individual beds could not be traced very far, but one bed was observed to continue for about 100 yds.

The tuffs are often excessively fine grained. Microscopic examination shows that finely divided angular quartz is an ingredient (*22293* and *22446*), in all likelihood derived from the comminution of schists (*see* p. 136).

Pitchstone Lavas.—Three separate outcrops of pitchstone occur within the South-west Vent, south-east of the Ben Hiant Intrusion (*see* Fig. 10). Each consists of one or two sheets that are gently inclined inwards towards the interior of the vent. As already stated, the sheets are concluded to be lava flows within the crater. The lowest outcrop consists of a single flow that is seen at one point to be interbedded with the tuffs and agglomerates of the vents. In the next outcrop only the lower portion of one flow is now on view, and there is evidence that it is earlier than an intrusion of Porphyritic Dolerite in the vent. The third outcrop may be later than the Porphyritic Dolerite, and includes two flows, of which the upper is at one place succeeded uphill by agglomerate. This agglomerate is the highest vent-material now seen in the South-west Vent, the centre of which is occupied by the great Ben Hiant Intrusion (*see* Fig. 19, p. 160).

On account of their internal structure the pitchstone sheets have been concluded to be lava flows. The evidence is best seen in the lowest outcrop east of Stallachan Dubha, which is crossed by a stream-gully affording a practically complete cross-section. The sheet consists structurally of lower, middle, and upper portions, of which the lower and middle portions display perfect columnar jointing. In the lower portion the hexagonal columns are arranged at right angles to the lower surface of the sheet, which rests upon slightly hardened tuff. In the middle portion the columns change abruptly in their direction and are arranged more or less parallel to the base of the sheet. These are of much smaller diameter than the upright columns below. Towards the top of the middle portion, small, oval-shaped amygdales are found which are lined with bluish chalcedony and centred with drusy quartz. In one place there are giant amygdales a foot in length, in which calcite is developed within the drusy quartz and chalcedony. At a higher level still, the pitchstone is unjointed and amygdales occur in increasing numbers till finally, towards the top of the sheet, they become very small and irregular in form, so that the rock may be termed a pitchstone-slag. The actual top is unfortunately not seen, for a gap of a foot or so separates exposures of the pitchstone-slag, above the left bank of the stream, from overlying agglomerate and spheroidally-weathering tuff. The three-fold structural sub-division of the sheet, however, seems sufficient evidence that we are dealing with a lava-flow and not an intrusion. The asymmetry negatives an intrusive origin, while the three-tier structural arrangement recalls that of the columnar basalt lava of Staffa.[1] This structural arrangement cannot be in the nature of an accident, for it is seen to be repeated in the upper of the two pitchstone sheets of the uppermost outcrop. In this case, lower and middle tiers of columnar pitchstone, exactly similar to those just described, are capped by amygdaloidal unjointed pitchstone, as is well seen at one point on the south-west side of the outcrop just east of a stream (Fig. 10). Inadequate exposure prevents us from determining whether the sheets develop the three-tier structural arrangement elsewhere. Other outcrops show either the lower tier with upright columns or else the unjointed amygdaloidal portion.

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[1] A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 17.

The columnar portions of the pitchstone sheets are often intruded by thin sills of stony pitchstone (21459). The sills are evidently due to the intrusion into fissures in consolidated pitchstone of portions still liquid. According to Bailey such auto-intrusion is developed in still more striking fashion in the case of the pitchstone lava of the Sgùrr of Eigg.[2]

Unlike the intrusive sheets of sheath-and-core pitchstone in Mull,[3] stoniness has not been developed along the joint-planes of the pitchstone lavas of Ben Hiant. This seems all the more remarkable, since the two rocks are practically identical in chemical composition (*see* p. 84). The reason for this difference we do not know. Stoniness, however, is developed as a secondary character in the Ben Hiant pitchstones where they come into contact with intrusive masses. For example the uppermost pitchstone becomes stony next to the great Ben Hiant Intrusion, a quarter of a mile south of the summit (21466). Stoniness in the lowest pitchstone, alongside the stream and near to the overlying intrusive mass of Stallachan Dubha, may also be ascribed to contact-action. It is again met with in the middle outcrop of pitchstone (21462), north of Stallachan Dubha, immediately next to the intrusion of Porphyritic Dolerite, and elsewhere this pitchstone is a normal black vitreous rock. The actual contact of the two rocks is not seen, but the development of the stoniness suggests that the Porphyritic Dolerite is later than the pitchstone. Conversely, in the case of an amygdaloidal extension of the upper outcrop of pitchstone above the Porphyritic Dolerite, the retention of its vitreous character in close proximity to the Porphyritic Dolerite may perhaps be regarded as evidence that the pitchstone is here the later of the two rocks. J.E.R.

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[1] G. A. Burnett *in* 'The Geology of Staffa, Iona, and Western Mull,' *Mem. Geol. Surv.*, 1925, p. 65.

[2] For a statement of the evidence for considering the Sgùrr of Eigg pitchstone to be a lava-flow, *see* E. B. Bailey, 'The Sgùrr of Eigg,' *Geol. Mag.*, N.S., Dec. vi., vol. i., 1914, pp. 296–305.

[3] E. M. Anderson and E. G. Radley, 'The Pitchstones of Mull and their Genesis,' *Quart. Journ. Geol. Soc.*, vol. lxxi., 1915, pp. 205–217.

NORTHERN VENTS

(EARLIER THAN CONE-SHEETS)

An irregular outcrop of vent-agglomerate and tuff occupies about half the countryside between Ben Hiant and the north coast at Faskadale.[1] As already mentioned, it has a roughly arcuate form, as if grouped about Centre 1 of Pl. II. Along its outer convex boundary the agglomerate comes against pre-Tertiary rocks, and its margin, so far as one can judge from imperfect exposures, is tolerably abrupt. Its inner concave border, on the other hand, lies against Tertiary basalt lavas and is extremely indefinite. The lavas have been greatly shattered by the vent-explosions, and there is no exact line of separation between them and the adjacent agglomerate. Moreover, as already stated, it is quite possible that the lavas have bodily slipped down into their present situation. Perhaps the amount of their descent into the vent was considerable, for in the Camphouse district only a narrow belt of agglomerate separates porphyritic basalt lavas from schists, without any intervening Mesozoic sediments. In their porphyritic character these lavas, indeed, recall the upper lavas of Mull rather than those of the lower or plateau group.

The agglomerate of this northern series of vents, besides containing abundant debris of basalt lavas, is rich in fragments of Mesozoic sediments and of gneiss or schist. It also includes numerous small blocks of acid rocks that are often porphyritic. These acid fragments cannot be attributed to the breaking up of any exposed country rock, and their presence suggests that the vent-explosions were connected with acid magma. E.B.B., J.E.R.

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[1] The Faskadale exposures and their abundant content of acid fragments have been described: Sir A. Geikie, 'Ancient Volcanoes of Great Britain,' vol. ii., 1897, p. 278.

The following localities may be given for masses of Mesozoic sediments of unusual dimensions:—

(1) At a point 400 yds. north-east of the mouth of the Achateny Water there is a block of false-bedded calcareous sandstone with obscure fossils, which measures 100 ft. in both directions. The bedding is nearly vertical. Similar sandstone is not known in the part of the Mesozoic sequence that remains intact east of the vent, but it is fairly abundantly represented by smaller blocks (up to 15 by 20 ft.) in the neighbouring agglomerate. The sandstone may be of Inferior Oolite age.

(2) A strip of brecciated black shale occupies the foreshore 500 yds. south-east of Ardtoe Island, north of Kilmory. Again, rock of this type is unknown to the east outside the vent. (There is some uncertainty as to whether the fossils listed on pp. 40–41 came from this mass or from another farther east).

(3) There is a good exposure of sandstone in a stream close to Kilmory school, and several others of sandstone and black shale within 500 yds. of this locality, especially towards the north-west and south-east. Individually these exposures give an impression of Mesozoic outcrops *in situ*, but thorough examination of the evidence leaves no doubt that the sediments occur as masses involved in vent-agglomerate.

(4) The Loch Mudle Fault, 1000 yds. east-north-east of Braehouse, runs along a little stream, and is drawn on the map as separating basalt lava on the east from vent-agglomerate on the west. An exposure shows 30 ft. of Lower Lias limestone dipping steeply away from a substantial outcrop of gneiss and towards the lavas. Both the limestone and the gneiss are probably enveloped in agglomerate, which, close at hand, contains small blocks of like materials.

There are only three exposed contacts of the northern vent-agglomerate with its outer wall. Where the edge of the vent reaches the coast, half a mile north-east of Kilmory, agglomerate is in contact with Lower Lias limestone (Broadford Beds) and the limestone is brecciated. A quarter of a mile inland a little roadside quarry shows agglomerate in contact with Lower Lias shales (Pabba Beds). The agglomerate overlies the shales, transgresses their bedding at a low angle, and is largely composed of their debris. Seven hundred yards farther south-east, Lower Lias limestone is seen with a vertical junction against agglomerate, and the agglomerate contains fragments of the limestone. The absence of extensive brecciation of the outer wall is very marked in all three localities. E.B.B.

As evidence of recurrent explosions within the complicated Northern Vent or Vent-complex, one may cite certain tuff-filled fissures traversing tuff and agglomerate. A good example occurs in the left bank of the Allt na Mi-Chomhdhail, 550 yds. upstream from the main road, and 1300 yds. due north of Camphouse. Another tuff vein, traversing basalt lava, is exposed in the floor of a roadside quarry 960 yds. south of Braehouse, and can be traced for 25 yds.

The vent-agglomerates, though later than the basalt lavas, seem to be earlier than all the intrusions with which they are visibly associated. They are cut by early major intrusions, cone-sheets, ring-dykes, and dykes. Exposures west of Faskadale Bay afford admirable illustrations of this relationship (*see* Fig. 16). In the most westerly outcrops, south of Rudha Groulin and Rudha Carrach, which are chiefly of tuffs, contact alteration due to the adjoining ring-dykes is very pronounced.

On the other hand, the agglomerates are later than some quartz-dolerite and leidleite intrusions (*see* p. 137). For example, they contain blocks of quartz-dolerite with acid veinings on the west shore of Faskadale Bay. Such inclusions afford an interesting demonstration of the occurrence of intrusions earlier than any seen *in situ* at the present level of denudation.

Glas Eilean Vent

(Later than Outer Cone-sheets of Centre 2)

A narrow strip of volcanic breccias has been mapped for two thirds of a mile north-eastwards from the south-east extremity of Kilchoan Bay. The breccias are best exposed on the promontory of Glas Eilean, which is separated from the mainland as an island at high tide, and along the shore to the north-east (Fig. 13). They mark the course of a linear vent that extends parallel to the trend of adjacent cone-sheets belonging to the Outer Set of Centre 2. Along the shore-section the vent is bounded by Tertiary basalt lavas to the north-west, and by Moine Schists to the south-east, both of which formations are cut by numerous cone-sheets. On the east side of Glas Eilean the cone-sheets cutting the Moine Schists constitute a veritable plexus of intrusions and are represented diagrammatically on Fig. 13.

A post-vent fault forms the north-west boundary of the vent on Glas Eilean, and is presumably responsible for the down-thrown lavas on this side. The fault-plane between vent-agglomerate and brecciated basalt lava belonging to the vent-wall is here vertical. The lavas are seen to dip steeply away from the fault, as indicated on Fig. 13. The fault then crosses the vent obliquely, interrupting the outcrop of agglomerate and breccia for a space, and then extends along the seaward side of the vent. There, the fault-plane, hading west, is again well seen, where a cone-sheet cutting the Moine Schists on the shore has been traced up to the dislocation. The sheet is deflected from its normal course close to the fault, and a fractured portion of it is seen as though extending along the fault-plane. Since it does not present a chilled margin against the fault-plane, as it does against the Moine Schists, the fault is concluded to be of later date.

In contrast to the well-defined junctions between country rocks and vent-materials where in faulted contact, no exact line of division exists elsewhere. It is a matter of opinion where to draw a line between brecciated country rocks belonging to the vent-wall and similar materials that form the greater part of the contents of the vent. There can, however, be no doubt that the brecciated country rocks mapped as lying within the vent have suffered vertical displacements from their original positions, for the vent-materials

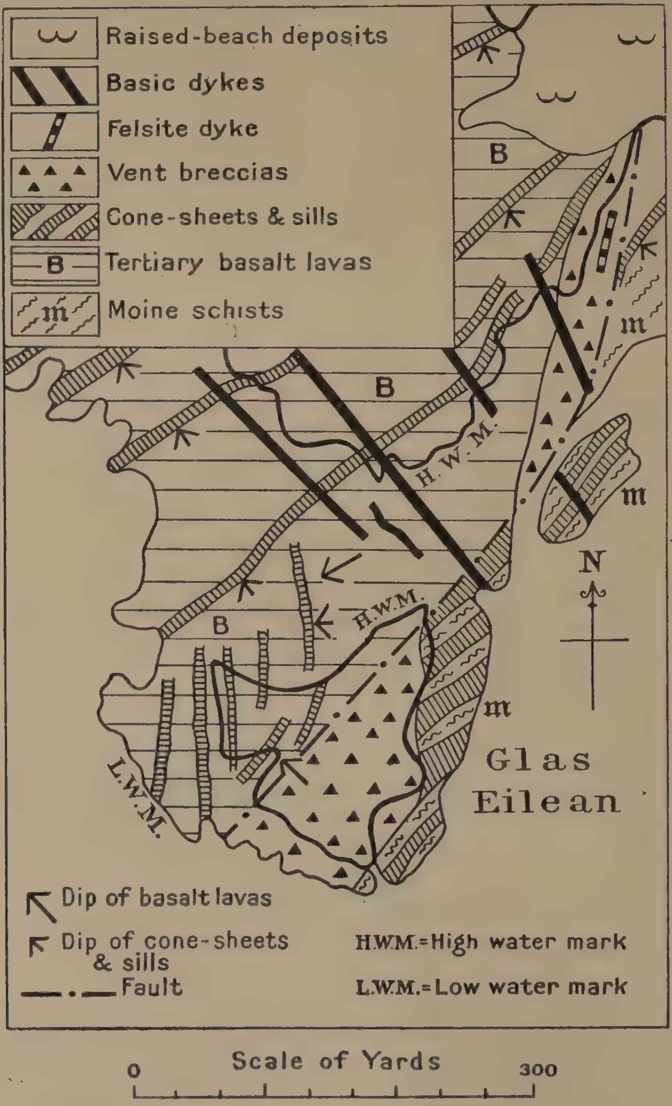
Raised-beach deposits
Basic dykes
Felsite dyke
Vent breccias
Cone-sheets & sills
B Tertiary basalt lavas
m Moine schists
B
B
B
m
m
m
H.W.M.
H.W.M.
L.W.M.
N
Glas Eilean
Dip of basalt lavas
Dip of cone-sheets & sills
Fault
H.W.M.=High water mark
L.W.M.=Low water mark
Scale of Yards
0
300

FIG. 13.—*Map of Glas Eilean Vent, south of Kilchoan.*

are heterogeneous, and fragments of different rocks are found side by side. For example, on Glas Eilean they consist partly of Jurassic limestone and sandstone not seen *in situ* in the vicinity, partly of the basalt lavas and schists that form the vent-walls. In addition, fragments of cone-sheets are abundant, and others of porphyritic basalt and of an acid compact rock are occasionally to be found. An interesting feature on Glas Eilean is the occurrence of large brecciated masses of Jurassic limestone traversed by cone-sheets. So little relative movement of the brecciated fragments composing each mass has taken place that the original relationship of the plexus of cone-sheets cutting the limestone can be easily made out. Coherent masses would seem to have been separated from the vent-wall in the first instance, and to have been brecciated by subsequent explosions while lying within the vent itself.

The explosions responsible for the brecciation are to be ascribed to an acid magma, of which the included acid fragments are a sign. Also, at one point, on the east side of Glas Eilean, a light yellow compact material, found under the microscope to be an acid tuff (p. 140), infills all the cracks and crevices of the breccias. To the unaided eye the veinings appear exactly similar to the net-veining characteristic of the margins of many ring-dykes in Ardnamurchan (*see* Fig. 34, p. 257). An intrusion of the acid magma that formed the tuff is probably represented by an irregularly running dyke of fluxion felsite or rhyolite that cuts the breccias and fine agglomerates of the vent near the head of the little bay north-east of Glas Eilean.

From what has been said above, coupled with the fact that not a single cone-sheet cuts the breccias, it is certain that the vent is later than the Outer Cone-sheets of Centre 2, or, at any rate, that portion of the belt of cone-sheets where the vent is situated. The parallelism between vent and adjacent cone-sheets seems to mark the vent as connected with Centre 2. It needs no great assumption to conclude that such a linear vent may be the superficial expression of a linear intrusion, below ground, guided by a ring-fissure, as already remarked in an introductory chapter (p. 77). J.E.R.

PETROLOGY

Agglomerates, Ben Hiant Vents.—One of the most striking features of the agglomerates that occur around Ben Hiant is the generally acid nature of the component fragments. Although a variety of rock-types enter into the composition of the agglomerates, it is patent that trachytes, rhyolites, and dacites constitute the bulk of the material, and point to the former existence of acid extrusive and intrusive rocks of which practically all other records are wanting.

The most prevalent rock-type met with is a bostonitic trachyte (22822, 22824, 22291). Generally it is a microporphyritic rock of which the phenocrysts are alkali-felspar and aluminous augite, while the matrix is most usually a fine-textured mass of small prisms of alkali-felspar, with scattered magnetite, minute scales of biotite and occasional large apatites.

The felspar phenocrysts in the microporphyritic types reach a quarter of an inch in length (22822), usually show a mottled structure, and are referable to perthite or anorthoclase. Their outline is somewhat irregular and they may occasionally show a nucleus of soda-plagioclase. Albite may also occur as individuals (22824).

The augite is subordinate to felspar both as regards the number and size of the phenocrysts. It builds small idiomorphic or rounded crystals of a greenish colour, and although prone to serpentinous decomposition is apparently an aluminous variety with a moderately large axial angle. We must not, however, dismiss the possibility of the former presence, in some instances, of a uniaxial augite of enstatite composition (22291), similar to that encountered in the Inninmore pitchstones of Mull and in the Ben Hiant pitchstones hereafter described.

The ground-mass consists commonly of a plexus of narrow short microliths of alkali-felspar, most frequently arranged in a fluxional manner, abundant grains of finely divided magnetite, and small limonitic and chloritic patches that appear to represent original biotite. In some instances seemingly original biotite in a fresh condition can be detected in the ground-mass (22822), but it is not always easy to distinguish between primary biotite and that developed as a result of a low grade thermal alteration which has affected much of the material in the Ben Hiant vents. A little quartz is usually present. It may occur as isolated patches within the porphyritic felspars, where it is probably of secondary origin, or scattered throughout the matrix in a manner that suggests an original constituent (22443).

That some of these trachytic rocks were in part glassy and possibly intrusive types, is suggested in some examples (22825) by areas that exhibit a pronouncedly acicular type of crystallization. In such cases the felspars of the matrix are slender and skeletal and have glass interiors. Augite exists as minute needles and magnetite in the form of rods. Structurally, rocks of this nature approach more nearly to pitchstones than to trachytes, but the phenocrysts are of alkali-felspar and augite, and are identical with those which occur in the more truly trachytic rocks described above. Thus, their affinity to the trachytes is established.

A porphyritic structure in the trachytes is not by any means universal, and several instances can be cited of rocks of trachytic aspect which are devoid of porphyritic constituents. In such cases the rock consists of a felted or fluxionally arranged mass of alkali-felspar prisms, with uniformly distributed minute crystals of magnetite, and small ragged flakes of biotite (22292).

Certain non-porphyritic microlithic rocks of a somewhat more basic composition are also represented (22445). These appear to have responded more readily than others to thermal conditions that existed in the vents, and which affected in varying measure most of the vent-material. They have a finely trachytic structure, produced by the disposition of microliths of alkali-felspar, but they are certainly richer in ferromagnesian constituents and poorer in silica than are the trachytes described above. In their altered condition, recrystallization of the base has frequently produced a definite minutely granular structure; and, under high magnifications, they show abundant scattered granules of recrystallized augite and magnetite, with some secondary biotite (22448, 22449).

From the agglomerate of Maclean's Nose comes a most beautiful fluxion rhyolite (21446) (Fig. 14, A). It contains abundant sharply crystallized phenocrysts of orthoclase, one to two millimetres in length, in a devitrified felsitic base that shows remarkable flow-banding, and an approach here and there to a sub-spherulitic structure. That the rock is a portion of a lava-flow associated with agglomeratic material is indicated by the fact that it has in its eruptive course gathered to itself a number of fragments of a variety of rocks. Amongst these xenolithic fragments plateau basalts preponderate, but there are also broken crystals of a greenish augite similar to the porphyritic augite of the trachytes.

In addition, a rock of dacitic composition (22823) is met with.

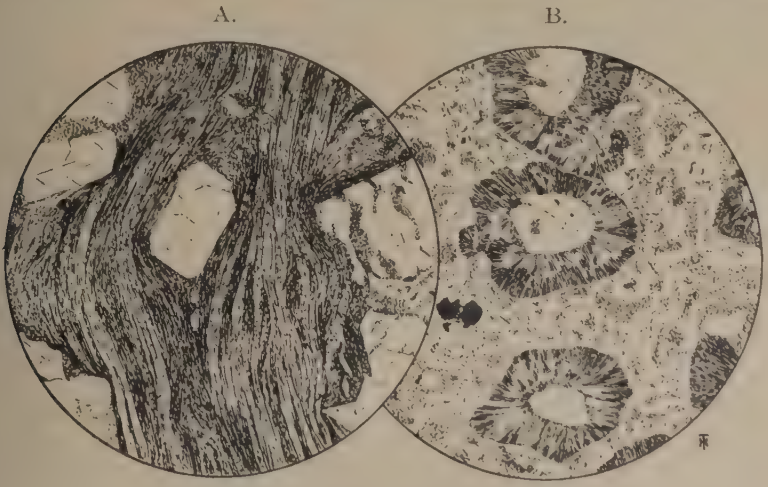

FIG. 14.—*Acid types from the Vents.*

A. (21446) × 20. *Rhyolite with well-developed fluxion-structure, from the Agglomerate of Maclean's Nose, Ben Hiant.*

B. (23599) × 20. *Spherulitic Quartz-rhyolite from East of Achateny Water. Showing phenocrysts of quartz surrounded by spherulitic growths of quartz and alkali-felspar, in a devitrified felsitic matrix.*

It contains small isolated and grouped phenocrysts of andesine, numerous small decomposed crystals of augite, and grains of magnetite, in a quartzo-felspathic matrix of variable texture.

The above account is descriptive of those rocks which occur in the agglomerates of Ben Hiant, and which cannot be matched in solid form in the accessible portions of the vent-walls. In petrological types they are most closely paralleled by the trachytic and rhyolitic rocks associated with agglomerates, and described by Dr. Harker, from Fionn Choire in Skye.[1]

Plateau basalts, some with porphyritic olivine (21447), and others non-porphyritic (22444), are prevalent constituents of the vent-agglomerates near the walls, and numerous large blocks of a big-felspar basalt (22447), some much shattered, are also encountered. This big-felspar rock is similar to certain porphyritic basalts that occur as north-west dykes (p. 347). It is dark grey and fine textured, and is closely packed with white or honey-yellow crystals of fresh felspar which range up to an inch or more in greatest dimension. Although the rock in the hand-specimen looks perfectly normal and unaltered, microscopic examination (26138, 22295) shows that in every instance it has been intensely shattered, but that the fractures and comminution have, in a large measure, been effaced by the healing process of metamorphism. The porphyritic felspars are of a medium labradorite, much twinned, occasionally albitized, and usually fringed with oligoclase. Augite is represented by moderately large pale-brownish crystals, and was evidently an original porphyritic constituent. Olivine was not an abundant mineral, but its presence is proved by the occurrence of small dark-green serpentinous pseudomorphs. Magnetite is plentiful, but is more or less restricted to the matrix. The matrix in which these larger porphyritic elements are embedded is an obviously disrupted mass of felspar, augite, and iron-ore, which has to a great extent suffered recrystallization as the result of thermal alteration. In it, small fragments of felspar have recrystallized, larger fragments have grown less basic fringes, augite has formed as small granules and prisms, magnetite has recrystallized, and a certain amount of biotite has been developed. These re-formed and regrown minerals are embedded in an ultimate residuum of oligoclase that acts as a base and is rich in apatite.

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[1] A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, pp. 58, 59.

Although all the basalt masses show equally the effects of shattering, some evince more intense thermal alteration than others. In the case of certain xenolithic masses in the Ben Hiant Intrusion (22452) the albitization of the felspars is more pronounced, and a greater amount of biotite has developed in the broken-down matrix at the expense of original iron-ore.

It is probable that the shattering was accomplished in the vent soon after the rock had consolidated, and that the metamorphism of the blocks was produced by the inherent heat of the crater, prior to their incorporation in the agglomerates. It is impossible to attribute the metamorphism of these masses to the thermal influence of any known intrusions, and further, they show a higher grade of metamorphism than that of the tuffs and other rocks with which they are now associated.

Bedded Tuff, Ben Hiant Vents.—The tuffs (22293, 22446) are often excessively fine-grained. Microscopic examinations show that they are typically clastic rocks, although igneous material bulks largely in their composition. They contain abundant small grains of quartz and minute flakes of white mica which are probably derived from the adjacent schists, but the greater part of their fine material, as is shown by broken crystals of plagioclase and augite, has had its origin in plateau basalts. Such large fragments as are encountered are also mainly of basaltic composition.

Agglomerates, Northern Vents.—The great mass of agglomerates which stretches southwards from the coast near Achateny towards

Camphouse has been made the subject of close study. It is more than usually rich in fragments of the various country rocks that bound the vents, but a representative collection of other types shows a general assemblage similar to that met with in the Ben Hiant Vents to the south. As at Ben Hiant, porphyritic bostonitic trachytes are extremely abundant (23598, 23601, 23605). They carry the usual phenocrysts of anorthoclase and albite, and aluminous augite which in some instances may be described as being abundant (23603). Soda- and potash-felspars frequently occur together, but occasionally either orthoclase (23605) or anorthoclase (23602) form the only felspar phenocrysts. The ground-mass, though usually microlithic, shows some variation in texture, and biotite is certainly not a noteworthy constituent. The petrographical characters of all these trachytes, however, and of those of the Ben Hiant Vents are so similar that there can be no doubt of their close relationship and probable contemporaneity.

Spherulitic quartz-rhyolites are also represented amongst the more acid fragments (23599, 23600) (Fig. 14, B). These are probably related to the fluxion rhyolite described from the South-west Vent of Ben Hiant (21446), but on the whole are more quartzose. One specimen (23599), collected from the east of the Achateny Water, contains abundant rounded phenocrysts of quartz surrounded by beautiful spherulitic growths, while similar growths without quartz-nuclei occur in the matrix. Another rock (23600) from the same district is similar as to the matrix, but does not carry the porphyritic quartz.

Amongst other fragments collected on the shore near Achateny farm, it is interesting to note definitely intrusive types such as quartz-dolerites, leidleites, and pitchstones. The quartz-dolerites are represented by rocks of moderately coarse type that resemble either the coarser varieties of basic cone-sheets (Talaidh type 23609), or the more vitreous quartz-dolerite of the main Ben Hiant intrusion (23608). Of rocks of augite-andesite composition, one (23606) may be described as a somewhat basic leidleite with the characteristic acicular type of crystallization.[1] It consists of irregularly grouped and distributed laths and skeletal growths of acid labradorite, elongated crystals of a brownish augite, and abundant finely divided magnetite, in a chloritic base that represents an original glassy residuum.

Another type (23607) is much more glassy. It shows numerous small phenocrysts of aluminous augite with moderate axial angle, and a few small albitized felspars, in a ground-mass composed of slender felted microliths of oligoclase, and a deep-brown residual glass. The rock is vesicular, the cavities being filled mainly with a deep-yellow iron epidote.

The origin of these intrusive types is obscure, but although of earlier date, they are certainly related petrographically to the Ben Hiant intrusions.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 281, 282.

Pitchstones of Ben Hiant (Anal. I and II, Table III, p. 84).—The pitchstones of Ben Hiant, as represented by the analysed and other specimens (21255, 21458, 21462), are dark-brown to black vitreous microporphyritic rocks through which small felspar phenocrysts are abundantly distributed. Their variation in colour is largely due, not to any inherent difference in composition, but to the extent to which devitrification of the glassy base has proceeded. Microscopically, the rocks are seen to contain phenocrysts of plagioclase and pyroxene in a pale-brown glass that is replete with microliths of felspar and augite, and contains in addition a little magnetite and apatite. The felspar of the phenocrysts occurs as well-crystallized individuals about one to two millimetres in greatest dimension. The crystals are usually twinned according to the Carlsbad law, but albite and pericline lamellation are frequently observed. Their boundaries are quite sharp against the glassy base, but the crystals are sometimes spongy and enclose patches and strings of glass. Most of the crystals show zoning that produces a gradual progressive extinction from the centre towards the margin. Their optical sign is uniformly negative and they appear to range from an exterior of basic labradorite to an interior that approximates to anorthite in composition. The only other microporphyritic mineral is a pyroxene, most commonly a pale-green augite, that occurs in moderate abundance as well-shaped prisms, usually of smaller dimensions than those of felspar. The crystals are elongated parallel to the c axis and show the usual simple terminations of augite. They are slightly pleochroic in shades of greenish-yellow. Optically, this mineral has a fairly wide

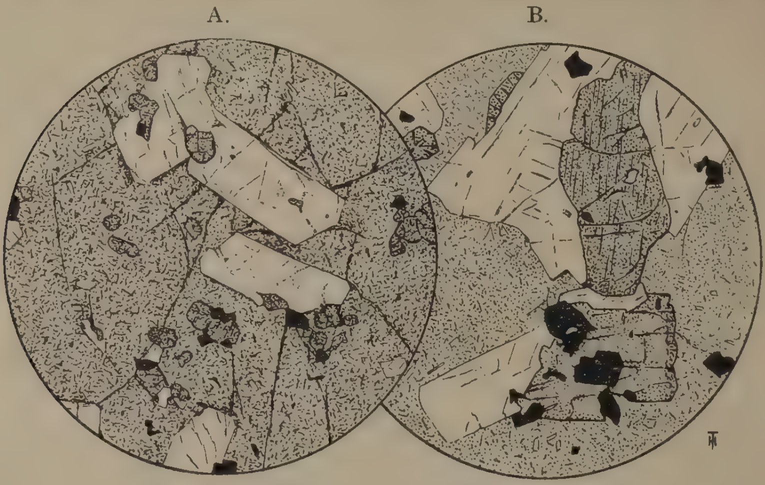

FIG. 15.—*Pitchstones of Ben Hiant.*

A. (21255) × 20. *Normal type. Porphyritic plagioclase and small crystals of enstatite-augite in a glassy base charged with crystallites.*

B. (21458) × 20. *Glomeroporphyritic group of hypersthene, augite, and plagioclase felspar in a brown glassy base.*

extinction, but its almost uniaxial character proclaims it a member of the enstatite-augite group, that is to say, a non-aluminous variety having the composition of enstatite and accompanied by a special set of optical properties. As found by Mr. Hallimond for the uniaxial augite of certain Mull pitchstones, it has an optically positive sign in common with the generality of augites. It is somewhat prone to alteration and passes into green serpentine (21461). A rhombic pyroxene that builds crystals of similar dimensions to those of the augite is sometimes present and is indistinguishable from the latter except by its straight extinction, biaxial character, and somewhat different pleochroism (21458).

The microliths of the ground-mass, scattered indiscriminately throughout the brown glass, are oligoclase and a greenish, presumably aluminous, augite. There is generally no arrangement of the crystallites indicative of flow, but perlitic cracks are a noticeable feature of the glassy base (22294). On devitrification the glass breaks up into small areas of acid plagioclase with some quartz, and it appears that this devitrification frequently commences around the porphyritic crystals (21460) or along perlitic cracks where such happen to be well developed (22294). Devitrification of the glassy base is exceptionally well marked when these rocks have come within the influence of some later intrusion, such as the Ben Hiant Porphyritic Dolerite (21462) or the great Ben Hiant Intrusion (21466). In the latter case there has been a more pronounced metamorphism with recrystallization and the production of finely divided biotite. The mineralogical characters and chemical composition of these rocks are practically identical with the inninmorite-pitchstones of Mull,[1] which showed an augite-andesite composition (Anal. A, Table III, p. 84) and were characterized by the presence of phenocrysts of basic plagioclase and enstatite-augite. Although the Mull occurrences were in the form of sills and the Ben Hiant pitchstones are undoubtedly lavas, there is no reason for not classing the latter with the inninmorites. Structurally these rocks are very similar to the well-known pitchstone of the Sgùrr of Eigg,[2] but chemically they belong to a less siliceous and more definitely andesitic type. This difference reveals itself mineralogically in the more basic character of the felspar phenocrysts, and chemically in an increase of the percentage of lime and soda at the expense of potash.

Glas Eilean Vent.—In the vent-breccia of Glas Eilean the fragments collected are chiefly of plateau basalts (24018) with others of more acid nature. One of the latter is an intrusive type that may be referred to as an albite-granophyre (24017). It consists of moderately large microporphyritic crystals of albite or albite-oligoclase, with pseudomorphs after augite, in a matrix composed of small crystals of albite and potash-felspar set in a granophyric base. The matrix of the agglomerate (24016, 24019) is especially interesting on account of its showing unmistakable signs of the explosive action of an acid magma. It is composed almost entirely of siliceous scoriaceous fragments and whisps of acid glass which show plainly the characteristic lunar and curvilinear form of glass fragments due to explosion. In the hand-specimen the dark basalt fragments strongly contrast with the lighter-coloured siliceous tuff that acts as their matrix. Strings of tuff (22237) occur, some few yards away from the true agglomerate, in the shattered plateau-basalt walls of the vent. As in the case of the matrix of the agglomerate the tuff is of a highly comminuted scoriaceous nature. It consists of a roughly laminated mass of minute chips of devitrified glass, some of the fragments showing well-defined fluxion structure, others being of the nature of disrupted pumice. The basalt lava against the tuff is of the ophimottled plateau type, and enters largely into the composition of the immediately adjoining fragmental material. H.H.T.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 282–284.

[2] A. Harker, 'The Geology of the Small Isles of Inverness-shire,' *Mem. Geol. Surv.*, 1908, pp. 170–176.

CHAPTER XII

TERTIARY MAJOR INTRUSIONS, CENTRE 1, ARDNAMURCHAN

In the eastern part of the Ardnamurchan igneous complex, a number of major intrusions are arranged around the same centre (1) as the main group of volcanic vents (*see* Pl. II, p. 71). They are at any rate later than those vents with which they are in contact. An upper limit to their age is set by the fact that such of them as extend westwards into the area traversed by the Outer Cone-sheets of Centre 2 are profusely cut by these sheets.

Some of the intrusions are dyke-like in form. Others occur as plugs or small bosses. The remainder are, in part at least, sheet-like, and follow the same direction as neighbouring cone-sheets attributed to Centre 1. Age relations between the various intrusions can only be determined in the case of a few individuals that are in contact with one another. As will be seen on Pl. II, the majority are widely separated by older and younger rocks. The dyke-like masses, together with the plugs and bosses, will be described first, in the present chapter. These consist of the following intrusions:

Dyke-like Intrusions—
(1) Porphyritic Dolerite of Glas Bheinn.
(2) Old Gabbro of Meall nan Con.
(3) Quartz-gabbro, west of Faskadale.
(4) Granophyre, west of Faskadale.
Plugs and Bosses—
(5) Trachyte, east of Ben Hiant (not shown on Pl. II).
(6) Porphyritic Dolerites of Ben Hiant, in two masses.
(7) Quartz-dolerite of Camphouse.
(8) Augite-diorite, east-south-east of Camphouse (not shown on Pl. II).

The dyke-like intrusions bear a close resemblance to ring-dykes, and are clearly arranged with reference to Centre 1. They are, however, too few in number to be collectively regarded as comparable to the ring-dyke complexes of the two later igneous centres. Their association with the massive cone-sheets referred to Centre 1, in a complex so largely consisting of vent-agglomerates, is noteworthy.

The Trachyte east of Ben Hiant is probably a boss and in rock-type resembles blocks contained in the Ben Hiant vent-agglomerates. The more important of the two Porphyritic Dolerites of Ben Hiant, south of the summit, is intruded as a plug, or perhaps as a crater-infilling, into the South-west Vent. The Quartz-dolerite of Camphouse appears to be a plug or boss. Lithologically it resembles the Ben Hiant Intrusion, which is described in the next chapter. The Augite-diorite is of insignificant size, but its peculiar rock-type is a matter of interest.

It is noteworthy that porphyritic structure (felspar phenocrysts) is characteristic of two of the dolerites, and is also a feature of the fine-textured marginal portions of the gabbros. In two cases, however, where the contacts of a gabbro and a dolerite intrusion with older rocks are seen, the actual chilled margins are devoid of felspar phenocrysts, though such phenocrysts become abundant within a few inches of the contacts (*see below*, and p. 146). The phenocrysts rapidly increase in size towards the interior, and no break in rock-continuity between chilled margins and the marginal porphyritic facies is discernible. The phenocrysts would thus appear, in these cases at least, to have formed after the intrusion came into position, and not at some lower crustal level (*see* p. 98).

In the Porphyritic Dolerite of Glas Bheinn and the Granophyre west of Faskadale, xenoliths of felspathic gneiss or schist are often very abundant. They are as a rule angular, but may also have rounded outlines, and are sometimes highly altered and almost completely resorbed.

(1) Porphyritic Dolerite of Glas Bheinn

This intrusion is given the same index-letter and colour on the Memoir-map as the Porphyritic Dolerites of Ben Hiant. These masses resemble one another in their consistently porphyritic habit (felspar phenocrysts), and in this character differ from the other major intrusions of Ardnamurchan, though these mostly belong to the Porphyritic Central Magma-Type. The Glas Bheinn intrusion is for the most part much more acid in composition than the Ben Hiant masses, being a quartz-dolerite or quartz-gabbro of rather acid type. At its eastern extremity, however, a more basic variation occurs, containing olivine and with less copious acid residuum (22453). There is no field evidence to show that this portion is an intrusion distinct from the rest of the mass, and it is probably a local variant. The two varieties agree in the relative number of their porphyritic felspars, which are also identical in size and composition. Throughout the intrusion, except at its eastern end, xenoliths of schist are frequently met with. At a point 300 yds. west of the summit of Glas Bheinn, xenoliths of gabbro occur in addition.

The elongate outcrop of the intrusion suggests that it is dyke-like in form. Steep margins are evident west of Camphouse, where the outcrop extends without deviation up the steep, easterly slopes of Glas Bheinn. A vertical junction with the Moine Schists is exposed where the north margin of the intrusion crosses the right bank of a stream, 700 yds. W. 10° N. of Camphouse. The porphyritic dolerite becomes free of felspar phenocrysts close to the contact at which it is very definitely chilled.

Along part of its course, the intrusion runs nearly parallel to, and sometimes coincident with, the southern bounding wall of the

Northern Vents. No actual junction with the agglomerates and brecciated basalt lavas mapped in contact has been located, but since the Porphyritic Dolerite is unbrecciated where it borders the vent, it is probably later.

At its eastern extremity, the intrusion enters the belt of country traversed by the massive cone-sheets of Centre 1, but is not seen to be cut by them. Whether the cone-sheets are cut off by the dolerite, or have failed to penetrate it, cannot be decided in the absence of exposed contacts. The intrusion is, on the other hand, crossed by a number of basic sheets striking north-west and gently inclined to the south-west. These sheets differ texturally from the majority of cone-sheets in their variolitic character (p. 194), but in this they resemble certain associates of the great Ben Hiant Intrusion. Further, the outcrop of the Glas Bheinn intrusion is interrupted by a probably later, plug-like mass of dolerite (the Quartz-dolerite of Camphouse), of exactly similar composition and texture to the coarser types of the Ben Hiant mass. There is thus some evidence pointing to the Glas Bheinn Porphyritic Dolerite being older than the Ben Hiant Intrusion. Since there are strong arguments for connecting the Ben Hiant Intrusion with the period of the massive cone-sheets, the scale seems turned in favour of regarding the cone-sheets as later than the Glas Bheinn intrusion.

The Glas Bheinn intrusion may thus be little later than the agglomerates in age. Other porphyritic basic rocks of early date are the big-felspar basalt blocks in the vents, and an identical type that occurs as early north-west dykes (p. 347), in addition to the Ben Hiant Porphyritic Dolerites already referred to.

The relative ages of the Glas Bheinn intrusion and the Outer Cone-sheets of Centre 2 are left in no doubt. From Camphouse westwards, the intrusion runs almost at right angles to the direction of the cone-sheets, and is profusely cut by them.

On the north side of Glas Bheinn a mass of felsite in contact with the Porphyritic Dolerite is also cut by the Outer Cone-sheets. A contact-specimen (22694) of the felsite and dolerite suggests the later age of the felsite (*see* p. 144). All these rocks are very highly contact altered at this place owing to their proximity to the Ring-dyke Complex of Centre 3. J.E.R.

Petrology.—The eastern extremity of the Glas Bheinn intrusion is a coarsely porphyritic dolerite that represents the intrusion in its more basic and least modified form (22453). The larger constituents of the rock are a basic plagioclase felspar, olivine, and augite with subordinate ilmenite or titano-magnetite.

The porphyritic felspars range up to a centimetre in length. They are moderately well formed, clean and not greatly zoned, while their optically negative character indicates a bytownite-anorthite composition. They show strong albite lamellation as the dominant twin-structure. Olivine builds moderately large crystals, but none of this mineral now remains in a fresh condition, its place being taken by talcose and serpentinous secondary products that are highly charged with magnetite. It is probable that the olivine was one of the iron-rich varieties.

Augite of a pale greenish-brown colour occurs in fairly large crystals, ophitically related to the smaller and less basic labradorite felspars that occur in the matrix.

There is a plentiful acid residuum that is composed of acid plagioclase felspar with a little orthoclase and quartz, in a chloritized base. In this mesostasis the crystalline elements exhibit an acicular and skeletal type of growth, and occasional blade-like crystals of augite are encountered which are charged peripherally with magnetite after the manner of the augites in the quartz-dolerite of Ben Hiant (pp. 170–1).

The main mass of the intrusion is a more acid quartz-dolerite with a copious acid mesostasis. The porphyritic felspars, where in contact with the acid partial magma, have usually lost their regular outline. They have been attacked with the resulting outgrowth of oligoclase on the more basic nuclei. This secondary growth of less basic felspar either forms a definite zone to the early felspar or stretches out in skeletal formation into the mesostasis (26097). Early formed augites, also, where in contact with the mesostasis, show signs of interaction. They are occasionally surrounded by a narrow reaction rim of fibrous hornblende.

The dolerite is strung with moderately coarse granophyric matter that has basified itself by the resorption of basic felspar and augite. Remnants of basic plagioclase with ill-defined boundaries and secondary growths of oligoclase, together with chloritized biotite, represent the results of interaction between basic and acid material. The granophyre itself exhibits a beautiful coarse graphic structure around square-ended crystals of oligoclase, which mineral encloses also the remnants of more basic plagioclase of xenocrystal origin (21485).

Near the summit of Glas Bheinn, on the northern edge of the Glas Bheinn intrusion, the dolerite is in contact with a felsite. As both rocks have come within the metamorphosing influence of the Faskadale Quartz-gabbro (Ring-dyke of Centre 3) and are more or less completely granulitized, it is difficult to be sure of their original relations. It would appear, however, that this felsite was a later intrusion than the dolerite, for it seems to have been basified by the digestion of doleritic material before contact alteration was impressed upon it.

In a specimen showing contact of the two rocks (22694), the basic portion referable to the altered dolerite contains basic plagioclase felspars edged and surrounded by a more acid variety, and a mosaic of alkali-felspar within which are developed minute granules and prisms of greenish augite and rhombic pyroxene, scales of fox-red biotite, and abundant finely-divided magnetite. The ferromagnesian minerals and magnetite are unevenly distributed and represent in their most abundant development localities occupied by the augite of the original dolerite. The felsitic portion contains phenocrysts of partly original perthite set in a fine mosaic of alkali felspar and quartz bespattered and strung by granules of both monoclinic and orthorhombic pyroxenes, and finely-divided magnetite. In the more purely siliceous areas the augite has a distinct green colour. The original basification of the felsite by incorporation of doleritic material is indicated by clots in the more felspathic portions of the rock which contain a basic felspar and are extremely rich in granular pyroxene, biotite, and magnetite, together with a little green pyrogenetic hornblende. These clots evidently represent doleritic fragments, but the whole rock, phenocrysts and xenocrysts included, is replete with granulitic pyroxenes resulting from a metamorphism later than the contamination. H.H.T.

(2) OLD GABBRO OF MEALL NAN CON

This small mass, a remnant of some larger intrusion, is only 400 yds. in length by 200 yds. wide. It obliquely crosses the north end of an elongate outcrop of older rocks on Meall nan Con, of which it forms a part, and which is bounded to west and east by ring-dykes belonging to Centre 3. In direction, it conforms to Centre 1.

The gabbro is highly metamorphosed. Its weathered surfaces have that bluish-black colour characteristic of many contact-altered rocks in Ardnamurchan which is correlated with an extreme cloudiness of the felspars as seen under the microscope, due to myriads of black specks. A northern intrusive margin of the gabbro is exposed against granulitized basalt of the screen, at which the gabbro becomes fine-grained and porphyritic. J.E.R.

Petrologically, the rock is a moderately coarse-textured olivine-gabbro (21514) that consisted originally of large crystals of olivine, interlocking crystals of basic labradorite, ophitic augite, and small patches of indefinitely shaped magnetite. The effects of its contact alteration by the adjoining ring-dykes are described in detail on p. 314. H.H.T.

(3) QUARTZ-GABBRO, WEST OF FASKADALE

This elongate intrusion extends from the west side of Faskadale Bay due west for 1¼ miles. It is accompanied on its northern side for three quarters of its course by a similarly oriented mass of granophyre, from which it is in part separated by screen-like masses of agglomerate. Both intrusions are arranged tangentially to Centre 1. They are seen in steep or vertical contact with the agglomerate-screen on the east side of Meall Buidhe Mòr, west of Faskadale Bay (*see* Fig. 16). This hill is not named on the Memoir-map, but its summit at 312 feet is indicated.

The Quartz-gabbro varies in rock-type from an olivine-gabbro poor in quartz in its more easterly portion to a normal quartz-gabbro or quartz-dolerite with well-developed acid mesostasis farther west. This western portion lies next to the Great Eucrite, which is there the outermost ring-dyke of Centre 3 (E of Pl. V, p. 201). It is consequently very greatly contact altered, together with cone-sheets belonging to Centre 2, by which it is freely cut (Fig. 16). Under these conditions, the interpretation of exposures becomes very difficult, but it is apparent that this portion of the mass, as mapped, includes more than one intrusion. For example, at a point a mile west of the head of Faskadale Bay, and just north of the margin of the Great Eucrite, acid quartz-dolerite is clearly intruded into a more basic quartz-gabbro, which resembles the type found to the east.

In its eastern portion, the Quartz-gabbro grades into porphyritic dolerite at its margin. This facies is best seen along the northern edge of the intrusion, where it is in contact either with the agglomerate-screen or with the later Granophyre. A junction with the screen is well exposed on the west shore of Faskadale Bay, where the intrusion is only 20 yds. wide. It there consists solely of the porphyritic variety, with a markedly chilled edge against the agglomerate to the south. At the actual contact, phenocrysts are absent (22644), but internally small scattered porphyritic felspars soon make their appearance. The latter rock grades rapidly into the normal porphyritic dolerite.

Intense shearing is developed in the outcrops along the shore. The rock is there riddled with steep planes of movement parallel to the direction of the intrusion. J.E.R.

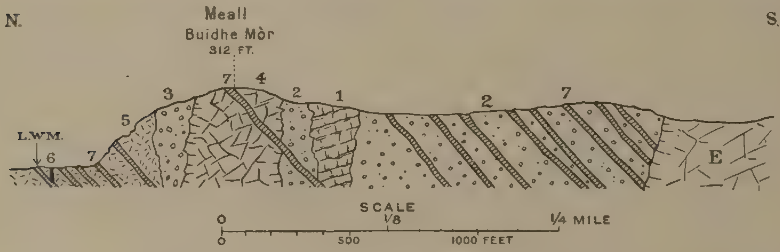

FIG. 16.—*Section, west of Faskadale Bay.*

1. *Basalt lava in vent.* 2, *Vent-agglomerate.* 3, *Screen of vent-agglomerate separating intrusions* 4 *and* 5. 4, *Gabbro of Centre* I. 5, *Granophyre of Centre* I. 6, *Basic E.N.E. dyke, seen to cut some cone-sheets and to be cut by others.* 7, *Cone-sheets of Centre* 2. E, *Great Eucrite Ring-dyke of Centre* 3. L.W.M., *Low-water Mark.*

Petrology.—The gabbro west of Faskadale Bay is a moderately coarse rock, but as described above is variable in character and composition. Further, it has suffered considerable thermal alteration and local crushing.

As represented by specimens collected near the centre of the mass (21596), it is a fairly coarse-textured doleritic gabbro composed of large interlocking crystals of zoned and much twinned labradorite, a brownish ophitic augite, a few moderately large patches of iron-ore, and relatively small pseudomorphs after olivine. The olivine is of an early generation and is idiomorphic towards the felspar. The rock even here is invaded by an acid partial magma, as is so common a feature of many of the Tertiary gabbros, that has resorbed the basic felspars with which it came in contact and caused them to grow albite-oligoclase extensions. This siliceous partial magma is, as usual, rich in apatite and has consolidated as a fine-textured aggregate of alkali-felspar and quartz.

The slight thermal alteration that the gabbro has at this point suffered at the hands of the Great Eucrite (E) shows itself chiefly in the conversion of the pseudomorphs after olivine into masses of fibrous green hornblende, and in the development of a similar hornblende with a little biotite in other parts of the rock where chloritic and serpentinous products had segregated.

As has been described above (p. 145) the mass becomes more variable and complex in its westerly extension, while to the east, towards the shore of Faskadale Bay, it takes on the form of a porphyritic quartz-dolerite and presents a fine-textured chilled edge to the agglomerate at its southern boundary. Microscopic examination of the rocks on the shore shows that all the mass has here suffered intense shattering that in many instances has almost completely obliterated original structures. Where least crushed (22646) the rock is a quartz-dolerite or quartz-gabbro composed of moderately large felspars, ophitic augite frequently edged with green amphibole, and iron-ore, with the usual acid residuum. The basic plagioclase felspars are all more or less albitized. In other specimens (22647) the rock is a comminuted mass of these constituents and shows the effects of intense crushing subsequent to its consolidation.

The southern fine-grained edge (22645) has escaped in a measure the crushing that comminuted the coarser rock, but even it has been affected (22644). It is a non-porphyritic rock composed of irregularly bounded laths of oligoclase felspar, scattered crystals and grains of magnetite, and fibrous hornblendic pseudomorphs after augite. The residual matter, of which there is no great quantity, consists of an aggregate of alkali-felspar and quartz with the usual abundant apatite. The rock is evidently a highly albitized representative of a medium-textured quartz-dolerite with prismatic to columnar augite, and as such recalls the Talaidh type of the cone-sheets (p. 187). Such complete albitization as that exhibited by the rock in question is much less common in Ardnamurchan than it is around the Mull centre, and its cause in this instance is obscure. It may, however, together with the pseudomorphing of augite by hornblende and the development of epidote in veins, be an expression of the metamorphosing influence of the granophyre bordering it to the north. H.H.T.

(4) Granophyre, West of Faskadale

As mentioned above (p. 145), the Quartz-gabbro west of Faskadale is accompanied on its northern side by an elongate outcrop of granophyre of later age. Screen-like masses of agglomerate, by which these two intrusions are separated along the greater part of their course, are absent just south of the summit of Meall Buidhe Mòr, indicated by the trigonometrical station at 312 ft. on the Memoir-map. The Granophyre is there markedly chilled against the porphyritic marginal facies of the Quartz-gabbro. The marginal granophyre differs from the main portion in being darker in colour, but both are alike in containing numerous angular xenoliths of schist. The junction seen is a clean-cut plane, inclined south at 70°. From this exposure near the summit, the Granophyre margin runs east directly downhill, but deviates round a broad portion of the agglomerate screen, while the contact between the screen and the adjoining Quartz-gabbro runs straight down to the shore. It is evident that the intrusive junctions on this hill-side are steep, and that the agglomerate masses are truly screen-like (Fig. 16).

Numerous cone-sheets cut the Granophyre, and are well seen along the shore between tide-marks, from where they extend up into the high sea-cliffs. In its eastern portion, the Granophyre is composed of an acid type. Westwards along the shore, half a mile west of the west side of Faskadale Bay, it changes to a felsite against a mass of black-weathering gabbro. The beach can here be reached down one only of the many hollows (geos) eroded in the high sea-cliffs along crush-lines. This is situated 300 yds. east of the headland at which the shore-line changes in direction to west-south-west, and is only a short way east of the outcrop of black gabbro. The gabbro is apparently a screen, 50 yds. wide, separating the acid granophyre from a less acid type to the west. The latter contains needly hornblende and is a basified granophyre (p. 149). Veins from it hybridize freely with the black gabbro. They are often coarse textured and appear to merge into the gabbro at their margins. The basified granophyre is thus different from the granophyre to the east of the screen in its marginal behaviour, and it is evidently a distinct intrusion. The gabbro-screen has not been found to extend inland, and the separation there of the two acid masses was not attempted, since exposures are sparse. For this reason, as well as on account of its small size, the screen has not been shown on the Memoir-map. J.E.R.

Petrology.—The granophyre that occupies the coastal region to the west of Faskadale Bay is represented by a number of specimens collected from the shore section. It has been contaminated to a considerable extent by the absorption of gneiss and possibly gabbro material but to the west is chilled against a gabbro screen. On the other side of the screen occurs a basified granophyre that has hybridized freely with the gabbro.

In its least contaminated portion (26096) the eastern part of the granophyre mass is a compact greenish-grey non-porphyritic rock. Under the microscope it is seen to consist of variously orientated, more or less equi-dimensional patches of alkali-felspar and quartz which exhibit a perfect micrographic structure. These patches usually have as nuclei a small idiomorphic crystal of acid plagioclase or orthoclase, and these are surrounded by a micrographic growth that becomes of increasingly coarse texture in an outward direction. The basic elements which may be regarded as foreign to the original composition of the rock are certain large carbonated crystals of plagioclase and moderately abundant patches of a dark-green strongly pleochroic chlorite that is frequently charged with magnetite. The chlorite from its outline is presumably pseudomorphous after biotite and represents the result of contamination by the absorption of gneiss. In other examples

(22640) the granophyric texture is on even a more micrographic scale and the rock as a whole appears to be more felspathic. In such cases partially resorbed augite and plagioclase may be detected and presumably result from contamination by gabbro material; while a fair amount of chlorite after biotite, of which some still retains its original character, may be referred to a gneissic source. In some parts of the mass partially resorbed xenoliths of siliceous gneiss can be made out, and then the surrounding granophyre (22638) has taken on the form of a fine-grained aggregate structure rather than the perfect granophyric structure previously described. The individual grains of quartz and felspar are separated from each other by strings and small areas of micropegmatite. Mica is well represented by chloritized flakes and patches of biotite.

Where more definitely contaminated by basic material (22639) the rock still shows a fine micrographic structure, but there is a distinctly greater development of small crystals of plagioclase felspar which indicates a rise in the soda and lime content of the rock as a whole. In addition, definite groups of large labradorite felspars, involving pseudomorphous matter that represents ophitic augite, are encountered, as also are chloritic pseudomorphs after biotite, and possibly after rhombic pyroxene.

The basic screen (22641-3), against which the eastern portion of the granophyre is chilled, is composed in part of a basic olivine-gabbro that locally becomes peridotitic in character. The most basic portion (22641) consists of moderately large crystals of bytownite-anorthite felspar, an ophitic augite, and abundant olivine. The latter is mainly fresh and occurs in both poecilitic and ophitic relation to the felspar. It is also frequently enclosed in poecilitic fashion by the augite. Hypersthene is encountered in small amount in close association with olivine, and a little biotite has developed in the vicinity of iron-ore. Where altered, the olivine has given rise to serpentinous and talcose pseudomorphs with the concomitant separation of magnetite. Other portions of the screen appear to be composed of a normal coarsely ophitic dolerite relatively poor in olivine.

The basified granophyre (22642) on the western side of the screen has attacked the olivine-gabbro that forms its eastern boundary. There is practically no metamorphism of the screen except at its contact with the granophyre, where the augite of the gabbro has developed into a brown pyrogenetic hornblende such as is found to be a common product of gabbro-granophyre hybrids. Rhombic pyroxene, now pseudomorphed, has also been produced as the result of interaction, basic plagioclases have been acidified, and iron-ores have caused the development of biotite in their vicinity. The granophyre itself contains numerous patches of partially resorbed basic plagioclase and augite, and carries abundant large crystals of apatite near its junction with the gabbro. It is a moderately coarse rock with good graphic structure in its base. It shows the effect of basification in the crystallization of long prisms of a green-brown hornblende, which give it the appearance of a craignurite in the hand-specimen. H.H.T.

5. TRACHYTE, EAST OF BEN HIANT

A small boss of trachyte forms a rocky knoll adjoining the Kilchoan–Glenborrodale road, opposite the 8-mile stone from Kilchoan. The top and sides of the mass consist of obviously chilled rock. J.B.S.

The rock is a fine-grained non-porphyritic biotite-trachyte (24466). It consists of a felted and fluxionally arranged mass of alkali-felspar microliths that measure less than one tenth of a millimetre in length. The felspars involve abundant minute prisms and grains of greenish augite, octahedra of magnetite, and fairly prevalent plates of bright-brown biotite. This rock is interesting mainly from the fact that it is distinctly alkaline in character and approaches in some measure the type of trachyte met with as fragments in the vent-agglomerate. It resembles more particularly the non-porphyritic trachytes of the vents, but may also be closely paralleled by the matrix of the porphyritic varieties. H.H.T.

6. PORPHYRITIC DOLERITES OF BEN HIANT

Two masses of this rock-type are met with, one to the north, the other south, of the summit of Ben Hiant (Fig. 10). The mass to the north is small and unimportant, and is surrounded by outcrops of the great Ben Hiant Intrusion, which is probably of later age. As mapped, it includes in addition to porphyritic dolerite a more acid rock (22455) resembling craignurite, which is presumably a distinct intrusion.

The larger mass to the south occupies an extensive hollow high up on the south-east side of Ben Hiant, and is excellently exposed in various stream-gullies. It is intrusive against tuffs and pitchstone lava contained within the South-west Vent of Ben Hiant, but is possibly earlier than other pitchstone lavas and agglomerates belonging to the same volcanic orifice (p. 129). It seems not unlikely that it is an old crater-infilling. Without doubt it antedates the Ben Hiant Intrusion, for it is considerably contact altered in exposures next to the latter.

The southern mass is very uniform in rock-type, a black fine-grained dolerite with abundant medium-sized porphyritic felspars, of a honey-yellow colour. These phenocrysts measure about half an inch in length and are considerably smaller than those of the big-felspar basalt that occur as blocks in the agglomerates. They are on the other hand much larger than the phenocrysts of the pitchstone lavas. Locally, the ground-mass becomes slightly coarser in texture, with abundant felspar needles visible in the hand-specimen. Spheroidal weathering is characteristic of exposures of the rock along the stream-gullies.

An intrusive margin against tuff is well seen in a deep gully cut by the most easterly stream but one that crosses the mass. The plane of junction of spheroidally-weathering dolerite and baked tuff is on view for 20 ft. on the gully-sides, and is inclined steeply north-west towards the dolerite at an angle of 80 degrees.

The dolerite does not send any veins into the tuff, the junction being perfectly even. It is, however, appreciably finer in grain at the actual contact. A steep junction against agglomerate is also evident at the south end of the mass, where the margin extends steeply uphill till terminated by the Ben Hiant Intrusion.

The Porphyritic Dolerite is also in contact on its south side with a small mass of pitchstone lava contained within the South-west Vent (p. 129). The actual junction of the two rocks is not seen, though its position can be located to within a few inches. Devitrification set up in the pitchstone adjacent to the dolerite is considered to be due to slight thermal alteration by the latter (21462). Along its north-east side, the Porphyritic Dolerite is apparently overlain by another sheet of pitchstone lava, above which an agglomerate scarp succeeds (p. 127). Here, too, the junction between pitchstones and dolerite has not been located, though very nearly determined. In this case the pitchstone retains its vitreous character close up to the dolerite, and would, therefore, seem to be later in age. If so, we must conclude that the dolerite was intruded during the infilling of the South-west Vent. Its junction with the tuff above described suggests its intrusion under no great pressure, and as already mentioned it may well be the infilling of a crater. J.E.R.

Petrology (Anal. IV and V, Table IV, p. 85).—This mass (21254) is a dark-grey fine-textured rock that shows in the hand-specimen abundant glassy-looking porphyritic crystals of felspar which mostly range from a quarter to half an inch in length. Microscopically it consists of porphyritic basic plagioclase, a brownish ophitic augite and a dark-brown glassy base.

The felspar of the porphyritic crystals, as judged by the mean refractive index and other optical properties, is a fairly basic labradorite, usually much twinned and occasionally somewhat zoned and albitized. The zoning is not very pronounced, but when present the ultimate product of separation was oligoclase. Albitization takes the form of irregular strings and patches of acid plagioclase within the crystals. Glass inclusions are of frequent occurrence.

The augite is often markedly ophitic (21254), and then encloses a smaller and later generation of labradorite felspar crystals. When the augite has developed in the matrix, free from interfering felspars, it has adopted a blade-like or semi-columnar habit with a distinct tendency towards idiomorphism.

Olivine, as in the main Ben Hiant mass (p. 169), is an occasional constituent. It occurs as small porphyritic individuals, but is usually replaced by secondary products (21464).

The glassy base has a dark colour due mainly to rods and disseminated magnetite or titano-magnetite. The iron-ores are more or less restricted to the base, but occur in sufficient quantity to give the rock as a whole distinct magnetic properties. Iron pyrites is often a subordinate constituent (21463). The matrix is not wholly glassy, for, in addition to the iron-ores, it contains abundant microliths and skeletal growths of oligoclase and augite (21464).

Occasionally, with an increased size in the development of the later felspars and a blade-like habit of the augite, the base assumes a sub-variolitic structure (21465) similar to that met with in some of the porphyritic basalts and dolerites of Central Type in Mull.[1] The proportion of glass to microliths and skeletal crystals in the base varies considerably from place to place. In some cases the base is semi-crystalline with feathery growths of felspar and augite, and contains irregular green patches and strings that suggest the original presence of chlorophæite (21254), as encountered in basic sills of the Lothians.[2] Devitrification of the base has resulted in the production of alkali-felspar and quartz, sometimes in fine graphic relationship, but on other occasions quartz forms small isolated patches (21463).

An interesting variant of this rock (22457) occurs in the north-western portion of its outcrop. It adjoins the Quartz-dolerite of Ben Hiant, and its peculiar characters are probably due to the influence of the main intrusion which has produced thermal alteration of this and other rocks with which it is in contact. It is a porphyritic basalt characterized by porphyritic crystals of labradorite. These larger crystals are disposed in a matrix composed mainly of laths of oligoclase-andesine felspar, granular to hypidiomorphic enstatite-augite, and a residual glassy base that has devitrified to a feathery growth of alkali-felspar and quartz. Many of the porphyritic felspars are mottled and spongy, presenting cavities filled with glass from the matrix. The mineralogical characters of this rock, particularly the presence of enstatite-augite, suggest a link between the dolerites of Ben Hiant and the pitchstone lavas (p. 139). The rock, however, has the appearance, like many other rocks in the Ben Hiant vents, of having been reheated and of having thereby undergone recrystallization to some extent. It is difficult to say in what measure the granular structure of this rock is original or has been produced by recrystallization, but I am inclined on the whole to regard its abnormal characters as being the result of reheating. H.H.T.

7. QUARTZ-DOLERITE OF CAMPHOUSE

This plug-like mass interrupts the outcrop of the Glas Bheinn intrusion just east of Camphouse, and is therefore believed to be of later date. The small oval area occupied by it is smooth and covered by grass, and is bounded by a raised rim of country rocks apparently baked by it. On its west side, it is bordered by the Camphouse river (Allt Choire Mhuilinn), in the high east bank of which it is well exposed. In the hand-specimen, the rock exactly resembles quartz-dolerite of Ben Hiant type, and sub-vitreous variolite-like veins traversing it are a further point of similarity. The rock is, however, too decomposed for microscopic examination.

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[1] H. H. Thomas *in* 'Tertiary Mull Memoir,' 1924, p. 163 and Fig. 23, A.

[2] R. Campbell and J. W. Lunn, 'Chlorophæite in the dolerites (tholeiites) of Dalmahoy and Kaimes Hills, Edinburgh,' *Mineralogical Mag.*, vol. xx., No. 110, 1925, pp. 435–440.

The intrusion may be regarded as later than the Porphyritic Dolerite of Glas Bheinn, as mentioned above. It is apparently later than the cone-sheets in its neighbourhood, since its smooth, grass-covered surface is unbroken by cone-sheet featuring, though many cone-sheets both to north and south are striking at it.

8. Augite-diorite, East-south-east of Camphouse

This tiny mass is too small to indicate on the Memoir-map, but is of considerable petrographical interest. As a rock-type, it is almost unique in Ardnamurchan. It is situated 1100 yds. E. 15° S. of Camphouse, and 100 yds. north-east of the track marked on the map which extends from the main road south of Camphouse across the north side of Ben Hiant. Exposures consist of a few rock-knobs west of a scarp formed of cone-sheets, and north of an outcrop of Lower Lias limestone. No contacts with these adjoining rocks are seen, but it may be presumed, at any rate, that the mass is of Tertiary age.

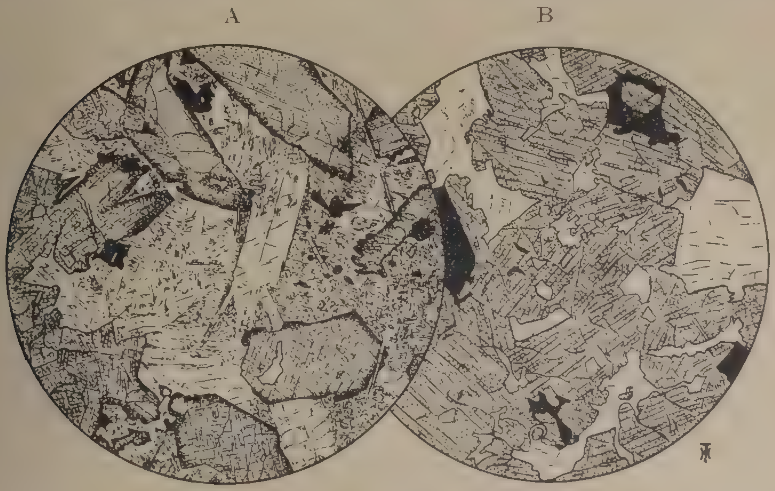

FIG. 17.—*Augite-diorite of Camphouse.*

A. (22226) × 6. *Felspathic variety. Idiomorphic crystals of augite with deep-brown or grass-green margins, partially albitized labradorite and perthitic orthoclase rich in apatite.*

B. (21512) × 20. *Portion of same mass showing a less alkaline and more doleritic facies.*

The rock is very variable in texture, passing rapidly from a fine-grained dolerite into a coarse pegmatitic gabbro, in which clear yellow sphene can be seen with the unaided eye. J.E.R.

Petrology.—For the main part this remarkable rock is a basic-looking intrusion of coarse gabbroid texture. It has large black crystals of augite that range up to an inch or more in length, and are separated from each other by a relatively small amount of opaque white felspathic matter. In the more acid varieties the augite crystals are more elongate and more obviously idiomorphic, while the felspathic matter is more prevalent and gives to the rock a dioritic texture. A feature of this more acid type is the abundance of light-brown sphene, which may be seen in the hand-specimen to form crystals and patches measuring as much as half an inch in length. In the coarser gabbroid rock (22225) the augite is a deeply coloured variety, and strongly pleochroic in shades of brownish-green and yellow or yellowish-brown, but occasionally there is that brownish-lavender tint suggestive of a titaniferous content. The felspar is labradorite and small in amount. It is frequently intergrown with the augite in graphic relationship, but is also moulded upon augite when this mineral has developed idiomorphic outlines. It is mostly much twinned and shows signs of albitization.

In slightly more felspathic varieties (21512) the augite is of similar composition and habit, but the rock as a whole takes on the somewhat unusual character of not only containing an alkaline residuum of perthitic composition, but developing large allotriomorphic patches of perthitic orthoclase. In the alkaline residuum and in the patches of alkali-felspar there has been a great concentration of apatite, crystals of which are practically unrepresented as inclusions in the minerals of earlier generation. It is the extremely felspathic varieties of this rock which are the most remarkable. In these (22226) the augite crystals present sharply idiomorphic boundaries to the felspathic matrix. In their central portions they are similarly coloured and have the same pleochroic scheme as those previously described. They are, however, commonly bordered with a deep-brown variety, and less frequently with a grass-green augite that has lower extinction values and presumably an alkaline composition. The extreme outer layer is of a rich clove-brown colour, strongly pleochroic and is referable to acmite. The felspathic constituents are, as before, of two kinds, plagioclase still being the dominant variety. The felspar occurs without ophitic or graphic relationship to the augite and is generally moulded upon it. In the main it consists of partially albitized labradorite in fairly large crystals that are zoned to the composition of oligoclase, but perthitic orthoclase, with its usual concentration of apatite, is liberally developed.

The rock considered as a whole is probably pegmatoid in character. The presence of abundant sphene removes it from the gabbros, while the high content of alkali-felspar suggests a relation to the essexites or theralites. It would, perhaps, be best to refer to the rock tentatively as a somewhat alkaline augite-diorite. Portions of the mass are, as the above description indicates, quite alkaline in character, but no felspathoid minerals have been detected; if they were ever present they must be represented by certain small chloritic patches that occur within the areas of perthitic orthoclase and which occasionally show idiomorphic outlines. The abnormal character of the rock as a whole, when compared with other Tertiary intrusions, cannot but cast some doubt, first on its age, and secondly on its mode of origin. If it is really related to the theralites there would be some difficulty, without more direct stratigraphical evidence than is forthcoming, in assigning to it a Tertiary age. Further, if a Tertiary intrusion, is it a normal type that represents a definite magmatic phase, or has it arisen through a process of hybridization or contamination? Fortunately the answer to both these questions has been furnished by the behaviour of certain acid veins that have emanated from one of the gabbros of the ring-dyke complex. A gabbro situated to the south-east of Rudha Groulin has given off felspathic veins that have penetrated, granulitized, and absorbed cone-sheet material (p. 293). Within the basic cone-sheet these veins (22636) show a coarsely crystalline texture, and consist of large greenish-brown crystals of augite, and laths of decomposed plagioclase in a matrix of perthitic orthoclase charged with apatite. Further, there has been a development of sphene. The mineral assemblage here met with is practically identical with that of the augite-diorite described above. Moreover, the structural relations of the various minerals to each other are similar. Such being the case, and these veins owing their character to the assimilation of basic material by an alkaline partial magma, it is probably safe to assume that the so-called augite-diorite of Camphouse is of Tertiary age, and of hybrid nature and origin.

The effects produced in the body of the cone-sheet by these veins are worthy of comment. The bulk of the rock has suffered recrystallization with a structure akin to granulitization; but in the process of reconstruction the incoming of alkaline matter has caused the augite to change over from the ordinary brownish variety of the cone-sheets (p. 187) to a yellowish-brown strongly pleochroic variety, which has a lower extinction angle, is identical with the augite of the more basic portions of the augite-diorite, and is certainly enriched in alkalis and ferric oxide. At the same time the granulitized rock is strung with veins of alkali-felspar, and has developed large crystals of sphene. H.H.T.

CHAPTER XIII

TERTIARY MAJOR INTRUSIONS, CENTRE 1, ARDNAMURCHAN (*continued*)

THE major intrusions referred to Centre 1 which remain to be described are as follows :

(1) Composite Intrusion of Beinn an Leathaid.
(2) Quartz-dolerite Intrusion of Ben Hiant.

The above intrusions are of large size and are in part sheet-like in form. Their outcrops follow the same directions as cone-sheets referred to Centre 1 (*see* Pl. II). In chemical and mineralogical composition they are also in part closely similar to these cone-sheets. There are consequently good reasons for assigning them and the early cone-sheets to the same intrusive period. But, since they are so much more massive, and since they possess individual peculiarities of form, structure and composition, they are described separately in the present chapter.

(1) COMPOSITE INTRUSION OF BEINN AN LEATHAID

This important composite intrusion (lettered GD on the Memoir-map) forms the upper part of Beinn an Leathaid, a prominent ridge that rises west of the Braehouse–Achateny road. It is probable, though not absolutely certain, that the intrusion is a sheet inclined gently towards the west-south-west. On this understanding its vertical thickness on Beinn an Leathaid must be rather more than 400 ft., of which the lower half consists of coarse, moderately basic rock, and the upper half of granophyre or felsite.

The more basic rock outcrops as an almost continuous cliff for two miles on the east face of Càthair Mhic Dhiarmaid and Beinn an Leathaid. The cliff looks like an escarpment of a sheet, and has rude columnar jointing inclined steeply towards the east-north-east. It is, however, impossible to establish with certainty the existence of a base to the supposed sheet. A pass called Bealach nan Each crosses the cliff north-west of Braehouse, but unfortunately at this point there is a local interruption in the outcrop of the basic material. Its margin, traced against basalt lavas on the north side of the pass, is irregular in shape and unchilled.

The granophyre or felsite forms the summit of the ridge and can be identified, for instance, at the cairn of Beinn an Leathaid, where it contains numerous xenoliths of schist and quartzite. Some way down the cliff-face east of the cairn, the granophyre merges through a narrow transition zone into underlying quartz-dolerite. The narrowness of this zone makes it improbable that differentiation has occurred *in situ*. It appears rather that the basic and acid material were differentiated in depth, and then injected more or less simultaneously.

The acid part of the intrusion extends as a narrow tongue across Bealach nan Each, where the basic part locally fails. Here, too, basalt lavas can be recognized west of the acid outcrop, but generally the western termination of the composite intrusion is obscured by later cone-sheets, grouped with the outer set of Centre 2. Good exposures of cone-sheets cutting the basic portion of the intrusion are furnished in Allt Rath a' Bheulain, south-west of Beinn an Leathaid.

The composite intrusion and the later cone-sheets are alike cut off by the Faskadale Quartz-gabbro, the outermost member of the Ring-dyke Complex of Centre 3. Exposures at Lochan Tom Mhic Iain, at the south end of the outcrop, show the basic portion clearly contact altered (26106). E.B.B.

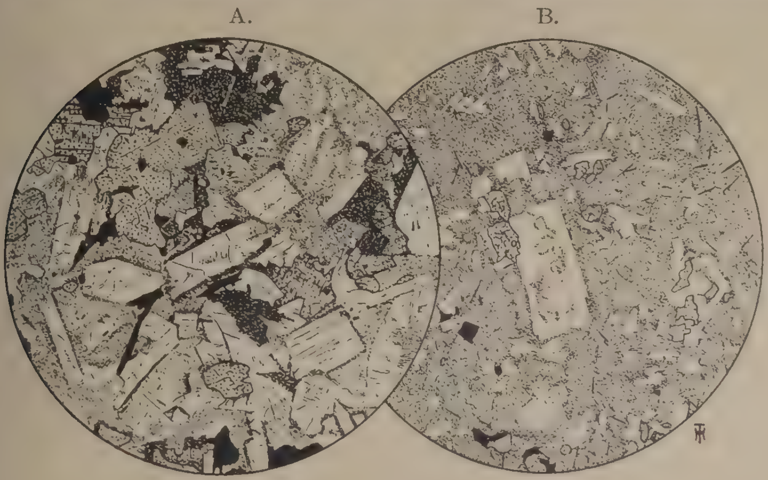

FIG. 18.—*Composite Intrusion of Beinn an Leathaid.*

A. (23463) × 20. *Lower basic portion of intrusion. The rock is composed of well-shaped crystals of zoned labradorite-andesine felspar, aluminous and non-aluminous augite, and a little hornblende in a matrix of alkali-felspar and quartz.*

B. (23459) × 34. *Acid upper portion of the intrusion. The section shows phenocrysts of acid-plagioclase felspar with subordinate ferromagnesian minerals in a fine-textured base that appears mainly to represent devitrified glass.*

Petrology.—This intrusion presents many points of petrological interest, for, in spite of its great thickness, it would appear that no portion of it is a strictly normal rock. As stated above, the sheet shows variation both in texture and colour from a grey moderately coarse-textured basic rock to a more acid paler and finer-grained upper portion. The change is gradual but pronounced and takes place through a relatively narrow transitional zone.

Even the lower basic portion, judged by the specimen collected (23463), is much more siliceous than most of the quartz-dolerites with which we are acquainted, and it also presents characters that are foreign to other rocks of this nature which are represented in Ardnamurchan.

Texturally the rock appears fairly uniform and moderately fine-grained. Felspars measuring a few millimetres in length and dark specks that represent ferromagnesian minerals are the obvious constituents. Under the microscope the rock is seen to consist mainly of well-shaped rectangular crystals of zoned labradorite-andesine felspar, edged with orthoclase and embedded in a beautiful micrographic base of alkali-felspar and quartz. The granophyric matter probably constitutes 20 per cent. of the rock and indicates a fairly high alkali-content. Augite is the dominant ferromagnesian mineral and is of two kinds, a non-aluminous almost uniaxial variety (enstatite-augite) and a normal aluminous augite with the characteristically wide axial angle. Both these minerals are pale-coloured and both have a tendency towards idiomorphism, but the enstatite-augite is more prone to decompose, to furnish ochreous pseudomorphs, and to give rise to indefinite brown patches within the body of the rock.

Besides the pyroxene, there is represented a deep olive-green hornblende that occurs as isolated somewhat irregularly bounded crystals, but more frequently either fringes or is intergrown with augite.

In addition to the quartz that enters into the constitution of the graphic intergrowths, this mineral occurs as rounded patches and also presents crystal faces towards an ochreous chloritic base that suggests for the rock an ultimate glassy residuum.

Iron-ore is represented by well-shaped octahedra, patches and plates of magnetite, and the rock as a whole is rich in apatite, more particularly in the micrographic regions which are crowded with slender prisms of this mineral.

When we examine the rock microscopically we find that the texture and composition is not nearly so uniform as might have been expected from the hand-specimen. It is noticed that there are distinct basic and acid areas, that pyroxene tends to segregate in one region and excessive micrographic matter in another, while much of the green hornblende appears to occupy an intermediate position, that is to say, where acid and basic areas encroach upon each other.

This type of hornblende, which is clearly pyrogenetic in origin, is known as a common result of hybridization between acid and basic igneous rocks. Dr. Harker, when describing the basified granophyres and hybrid rocks of Marsco in Skye, stated that this hornblende, which may be either idiomorphic or replacing augite, is constantly the dominant mineral of the hybrid rocks.

From the general abnormality of the rock-mass in question, and from a comparison with the rocks of Skye, I would suggest that this sheet is allied in origin to marscoite. It may be, therefore, that the mass is hybrid in nature, was intruded as a unit, and was followed immediately by acid magma that has further modified the earlier intrusion and formed a relatively narrow transitional zone.

The rocks of this passage-zone (23460–2) show but little change in their actual mineral components, the chief variation being an increase in the amount of micrographic matter at the expense of the ferromagnesian and purely felspathic constituents. At the same time, however, there appears to be a tendency for the idiomorphic felspars to diminish in size and to become more acid in composition. In the uppermost part of the passage-zone the felspars are reduced to small rectangular individuals that have the composition of oligoclase. In this portion of the mass, also, the interstitial micrographic matter becomes exceedingly fine-grained and appears to be replaced locally by devitrified glass. The acid, upper and presumably latest portion of the intrusion (23459), has what may almost be described as a pitchstone base. The rock is extremely patchy, the pitchstone-like material involving microporphyritic areas that exhibit a structure similar to that of the upper portion of the transition zone.

This acid part of the intrusion contains a number of accidental xenoliths of a siliceous nature. One of quartzite (23459) shows that the quartz grains have been fritted with the development of fringes of tridymite, which mineral has as usual reverted to quartz with a retention of its crystal form. Where in contact with the igneous rock, such xenoliths have determined the growth of augite around them. Long blade-like crystals have been developed, some of which are fresh and others pseudomorphed by secondary products after the manner of enstatite-augite. H.H.T.

(2) Quartz-dolerite Intrusion of Ben Hiant

This intrusion forms the greater part of Ben Hiant, including the summit and its surrounding cliffs and crags (Pl. I, A). It has been the subject of some controversy between two previous observers, Prof. J. W. Judd and Sir Archibald Geikie.[1] To this, reference has been already made (p. 121). While Geikie has rightly pointed out the intrusive origin of the dolerite, his conclusions are not confirmed in all respects by recent survey work. He regarded the mass as built up of a great series of sheets, which he included with his group of basic sills (the cone-sheets). The evidence bearing on this point will be fully discussed below.

In mineralogical composition the Ben Hiant quartz-dolerite differs from the type characteristic of the cone-sheets, though their chemical analyses are practically identical (p. 82). Olivine is generally present in the Ben Hiant type, and also a variolitic ground-mass more or less segregated in patches. This variolite is unlike the more acid mesostasis of the majority of cone-sheets. It has been noted in the case of one cone-sheet, which occurs north of the Ben Hiant Intrusion and approximately along the same line of strike.

The most important variation in rock-type throughout the mass is comprised in a local sheet-like development of variolite, to be described in detail below (p. 166). Also, considerable changes in texture occur from place to place. Along the shore on the western side of the hill, where the intrusion rises from sea-level as a dyke-like mass, coarser varieties approaching gabbro are met with. The outer parts of this dyke-like portion of the intrusion are composed of the coarse-textured dolerite, while the centre consists of the normal, finer-grained variety. The two varieties appear to grade into one another, though they may perhaps represent separate injections. At higher levels on the hill there is considerable variation in texture, though the rock is nowhere truly gabbroic. No sharp contacts between portions differing in texture could be made out, such as would suggest that the mass is made up of multiple injections.

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[1] Sir A. Geikie, 'Ancient Volcanoes of Great Britain,' vol. ii., 1897, pp. 318–322.

The mass is everywhere traversed by close-set joint-planes which are vertical or steeply inclined (*see* Pl. I, B). To these dominant planes of weakness the steep faces and precipitous cliffs characteristic of Ben Hiant are due. The joints extend upwards through the mass without any ascertainable interruption, as may be seen for a vertical distance of some 500 ft. on the precipitous north side of the hill. On the steep, though less abrupt, southern side, the closely-jointed dolerite has been weathered back in three or four great tiers, one above the other, which give this part of the hill a bedded appearance. A close examination failed, however, to locate any intrusive contacts where the bedded aspect would lead one to expect them.

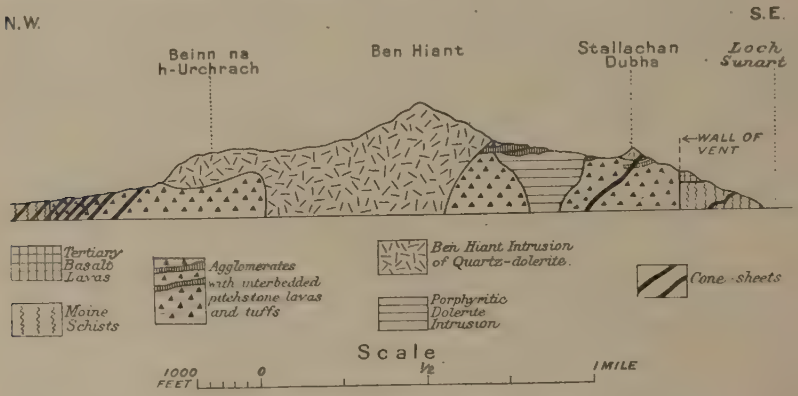
N.W.
S.E.
Beinn na h-Urchrach
Ben Hiant
Stallachan Dubha
Loch Sunart
WALL OF VENT
Tertiary Basalt Lavas
Moine Schists
Agglomerates with interbedded pitchstone lavas and tuffs
Ben Hiant Intrusion of Quartz-dolerite.
Porphyritic Dolerite Intrusion
Cone-sheets
Scale
1000 FEET
0
½
1 MILE

FIG. 19.—*Section across Ben Hiant.*

The intrusion is traversed by a few north-west lines of crush, the positions of which are marked by straight-running hollows. These extend approximately parallel to the face of the hill on its western side. When viewed from a distance, from the neighbourhood of Kilchoan, the hill thus presents a false appearance of flat bedding (Pl. I, A.). Other denudation-hollows extend steeply up this hillside, and seem to indicate sheet-margins inclined at about 35 degrees to west-north-west, corresponding to the inclination of the cone-sheets of the district. No evidence of intrusive contacts, however, could be found where rock is continuously exposed across such apparent sheet-contacts. Further, the jointing in the dolerite at such places does not run at right angles to the apparent sheet-margins, but remains vertical. The lines of weakness along which weathering has acted are believed to be cone-sheet fractures, which were not intruded by magma. Only one instance of a cone-sheet cutting the Ben Hiant dolerite is known (p. 166). It is noteworthy that the cone-sheet concerned extends continuously up through 1000 ft. of agglomerate but only penetrates a sheet-like outlier of the dolerite for a few feet.

A perfectly developed set of prismatic joints, enclosing six-sided columns a yard or more in diameter, is developed at one point in a basal portion of the mass. The locality is on the north side of Ben Hiant, alongside the most easterly stream traversing the dolerite, 300 yds. south of a cross-country track shown on the Memoir-map. The rock is much weathered, but the margins of the columns have proved more resistant than the softer interiors. They form slightly raised, six-sided rims, each separated by a joint-plane from the rims of adjoining columns. The hardening of these margins must be connected with the joint-planes, and is presumably due to the action of vapours escaping from later-consolidated interior portions of the mass. Similar hardened rims to hexagonal columns of basalt lava, hitherto unrecorded, were observed in the Island of Mull, near the summit of Coire Bheinn to the west of Ben More. In this case the rims were grey in colour, as though pneumatolized, while the interiors were of normal brown-weathering basalt.

FORM OF INTRUSION

The Ben Hiant Intrusion rises abruptly from sea-level on the west side of the hill as a dyke-like mass (*see* Fig. 19). At an altitude of 400 ft., on its north side, this mass spreads outwards to flatly override agglomerates of the Ben Hiant vent and the older bedded rocks. On its south side a similar extension at a height of over 1000 ft. is indicated by an outlying cake of dolerite on Stallachan Dubha. When followed uphill along the centre of the dyke-like portion the dolerite grades into variolite, which is interpreted as a quickly chilled upper surface of the intrusion (p. 168). This western portion of the Ben Hiant dolerite is, therefore, of mushroom shape.

The intrusion of the dolerite through the materials infilling the south-west Ben Hiant Vent, its mushroom shape, and its probable termination upwards near to the present denudation-surface, render it likely that the mass is a vent-infilling. On the other hand the eastern portion of the intrusion follows a different plan. On the lower ground north-east of the summit, tongues from the Ben Hiant dolerite extend out into the country rocks. These tongues follow the direction and inclination of the adjoining cone-sheets, from which they cannot indeed always be distinguished in the field, Towards the central mass of Ben Hiant they come together to form one continuous dolerite outcrop, but their sheet-like form is in certain cases still apparent. The absence of chilled margins, or sharp junctions, in exposures where such sheet-like masses are seen to join, is unlike the behaviour of cone-sheets, which are invariably chilled when in contact with one another. The tongues from the Ben Hiant dolerite also differ from neighbouring cone-sheets in having a lower inclination, usually not more than 10 degrees. Two possibilities as to their origin may be considered. They may be either cone-sheet feeders of the main mass of the Ben Hiant Intrusion, or they may be offshoots from the latter along cone-sheet fracture-lines. Taking into consideration the mushroom form of the great mass of dolerite comprising the west part of the intrusion and the absence of intrusive margins to the sheet-like masses where seen in contact, the latter explanation is here adopted. It would seem probable that the cone-sheet fractures were formed simultaneously with the intrusion of the main mass of the dolerite.

Sir A. Geikie, in his account of Ben Hiant, has referred to the sheet-like apophyses described above, and has mentioned that one of them extended for more than a mile from the main mass. They no doubt greatly influenced him in his conclusion that the Ben Hiant Intrusion was built up of a series of sheets. In the absence of ascertainable sheet-margins at any point within the Ben Hiant mass, his conception can, however, scarcely be maintained, especially since the rock type concerned is of hypabyssal character and therefore prone to chilling.

The field evidence on which the above general account is based is given below.

North-west Margin.—The north-west margin of the Ben Hiant Intrusion outcrops on the western shore of Ben Hiant which may be reached from the direction of Kilchoan by a track that skirts the coast from Mingary. Above high-water mark, in the angle of a bay north-west of the margin, Kilchoan Schists, with felspar pebbles in certain layers, are exposed and dip south-east. Near by, on the shore, a porphyritic basic sill is intruded along the bedding of the schists, while farther inshore a cone-sheet may be seen with contrary inclination to north-west. About 30 yds. south of the cone-sheet the Ben Hiant dolerite is first exposed, but its contact with the schists is not on view. Outcrops on the adjoining steep hillside are, however, sufficiently numerous to show that this margin of the dolerite is practically vertical. At a height of about 400 ft. the margin abruptly turns north-west along the face of the hill, and the dolerite forms a well-marked scarp above steep slopes composed of schist overlain by Trias breccia and Lower Lias limestone. The actual margin of this flatly-disposed portion of the dolerite is obscured by fallen blocks. From this point, the scarp continues round to the north-west side of Beinn na h'Urchrach, where it extends for a mile as a very strong feature. The base of this escarpment coincides almost exactly with the margin of the intrusion against brecciated basalt and agglomerate, except where a broad tongue of the dolerite is shown on the map projecting northwards for a quarter of a mile. The northern margin of this tongue is ill-defined, largely because of discontinuity in rock-exposure, which increases the difficulty of separating the Ben Hiant dolerite from outcrops of cone-sheets.

Sir A. Geikie has given an account, accompanied by illustrations, of what he terms the massive sill of Beinn na h'Urchrach.[1] There is, however, no similarity between his description and the Beinn na h'Urchrach escarpment, which undoubtedly forms an integral part of the Ben Hiant Intrusion. On the other hand, Geikie's description and figures are evidently based on close observation in the field, and the intrusions with which he was concerned seem obviously to be the cone-sheets of this Memoir. An explanation of the difference between his conclusions and our own concerning Beinn na h'Urchrach seems to be that Geikie has applied this name to a prominent ridge farther north, called Beinn nan Losgann, to which his observations are closely applicable. But since Geikie's illustrations are not accompanied by a scale of distances one cannot be altogether certain as to this.

South-east Margin.—In form, the south-east portion of the Ben Hiant Intrusion bears a close resemblance to that just described. It is everywhere bounded by the older rocks that fill the Ben Hiant vents. A junction with these materials is seen on the western coast, below high-water mark, where the dolerite is in irregular contact with a highly baked basaltic rock, and is quite unchilled. For a short distance along the shore within this margin, the dolerite is traversed by acid veins, a frequent marginal feature of the ring-dykes, but not seen elsewhere within the Ben Hiant mass. It is noteworthy that these veins are only developed at this, the lowest exposed part of the intrusion. Further, as already stated (p. 160), this portion of the dolerite is more gabbroid in texture than at higher levels, which is in keeping with the foregoing evidence of its crystallization under relatively deep-seated conditions.

The margin extends from the western shore up steep slopes to a height of 1200 ft., and is highly inclined to the north-west (Pl. I, B). From this point, it continues along a more level course at the base of high crags in which the characteristic close-set vertical jointing of the dolerite is well seen. It then changes direction to curve around the eastern side of the intrusion, and across a spur north-east of the summit. It there enters the north-east sector of the intrusion, a description of which, from Beinn na h'Urchrach to the spur just mentioned, will be given below.

There remain to describe two isolated masses of quartz-dolerite of Ben Hiant type which occur on the south side of the hill. The larger mass forms the peaks of Stallachan Dubha (Fig. 10, p. 122), and is separated from the Ben Hiant Intrusion proper by a wide shallow hollow floored by the vent-rocks. It forms a cake-like mass, with close-set almost vertical joints, resting upon agglomerate and pitchstone lava of the South-west Vent. Its flat base is clearly displayed along two hollows that cross the mass, and indeed nearly divide it into three separate parts. There can be little doubt that it is the denuded remnant of a sheet-like extension southwards of the main Ben Hiant Intrusion, an extension that has its parallel on the north side of Ben Hiant in the over-riding escarpment of Beinn na h'Urchrach (p. 162). The beautifully displayed jointing of the Stallachan Dubha crags is a feature in common with the main portion of the intrusion.

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[1] Sir A. Geikie, 'The Ancient Volcanoes of Great Britain,' vol. ii., 1897, pp. 321, 322, and Figs. 326, 327.

A contact of the Stallachan Dubha dolerite with baked tuff is exposed at the base of a crag on the north side of the mass, north of the centre peak and close to a stream. The dolerite is fine-grained at the actual junction, but does not develop a chilled edge. When traced up the crag above, this marginal type is seen to grade into dolerite of normal grain within a few yards.

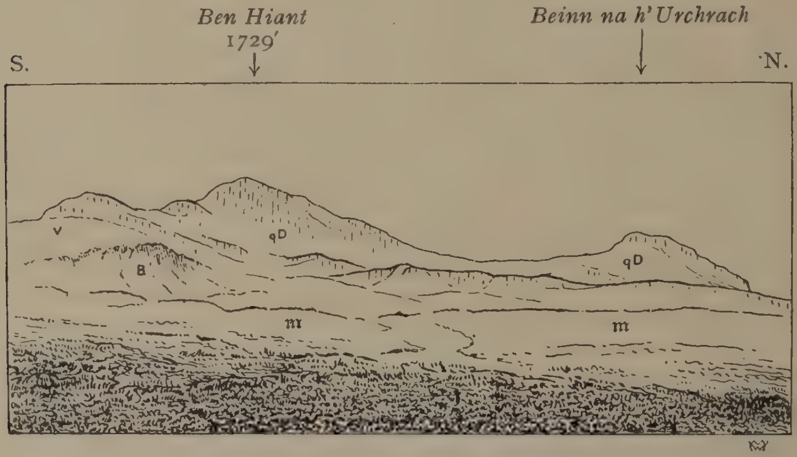

FIG. 20.—*View of Ben Hiant from east.*

m, *Moine Schists.* B, *Tertiary basalt lava.* V, *Vent-agglomerate.* qD, *Ben Hiant Intrusion.*

The second isolated outcrop of quartz-dolerite of Ben Hiant type is met with due east of Stallachan Dubha at a margin of the South-west Vent (Fig. 10, p. 122). It is seen in a stream-section between the vent-agglomerate and the vent-wall that is there composed of schist. The form of this little mass is quite obscure.

North-east Margin.—The irregularities in the behaviour of the north-east portion of the Ben Hiant Intrusion have been already briefly stated (pp. 161–2). These complications begin beyond the north-east end of Beinn na h'Urchrach. A continuous outcrop of older rocks extends uphill and southwards across this end of the great Beinn na h'Urchrach escarpment, so that there appears at this point to be a northerly inclined base to the intrusion. The older rocks consist of agglomerate and Lower Lias limestone and shales, and are exposed mainly in a stream-section. Farther east, in a hollow north of the central mass of Ben Hiant, the form of the dolerite becomes very complex in detail. Scarp and dip-slope featuring is developed which is to be ascribed to the intrusion of dolerite into inclined fissures, but such apparent apophyses appear to be interconnected by a complicated series of less massive injections. For example, in a stream half a mile north of Ben Hiant summit, in which Lower Lias limestone and sandstone intervening between apophyses are exposed, these sediments do not form a continuous outcrop, but are irregularly traversed by dolerite at intervals.

East of the stream last mentioned, a ridge is formed of a well-exposed sheet-like apophysis, having a dip-slope inclined at about 10 degrees to the west, and a high scarp to the east. This scarp borders a stream that winds northwards for a mile to enter a deep hollow south of Loch Mudle, eroded along the course of the Loch Mudle Fault. The scarp-feature is composed of cross-jointed dolerite, and is underlain by the much weathered columnar dolerite that has been already described (p. 161). Exposures are continuous between the base of the scarp and the much weathered dolerite, but a careful search failed to locate any sign of intrusive contact between the two types of rock. The two varieties of dolerite would appear to have been injected almost simultaneously.

The well-marked scarp extends southwards to ascend the eastern spur of Ben Hiant already referred to (p. 163), where it has a westerly inclination of 20 degrees (*see* Fig. 20). On this ridge, also, it is underlain by an easily weathered variety, which is largely covered by grass. Northwards from the exposure by the stream where the two varieties are seen together, the dolerite continues out into the schists for more than a mile as an isolated tongue, which has been mapped by Mr. E. B. Bailey. This extensive apophysis is composed of both hard and soft varieties, the former frequently containing abundant xenoliths of schist, which are also found in its more southerly outcrops. In the hollow at the south end of Loch Mudle, it terminates against the Loch Mudle Fault, by which its outcrop is shifted to the south-east, where it is seen again on a ridge east of the fault-hollow (*see* Pl. II). There, the characteristic xenoliths of schist are often abundant. The direction of this elongate tongue is exactly parallel to the trend of adjacent cone-sheets referred to Centre 1. The amount of its inclination, however, seemed to the writer to be distinctly less than that of the cone-sheets.

AGE RELATIONS

Much of the evidence bearing on the date of intrusion of the Ben Hiant dolerite has been given in foregoing pages. This, together with additional facts, will now be briefly stated, and their significance discussed.

Along its south-east margin the dolerite is in steep contact, from sea-level through a vertical distance of 1200 ft., with the materials infilling the South-west Vent. This western dyke-like portion of the mass may therefore be said to be intruded with marked discordance through the vent-materials, since the latter are found in well-exposed sections to consist mainly of flatly interbedded tuffs, agglomerates, and pitchstone lavas. The later date of the dolerite is demonstrated by actual contacts (pp. 163, 164). Further evidence of this is supplied by the contact alteration which, as Dr. Thomas finds under the microscope, all vent-materials show in proximity to the dolerite. In the field the contact alteration is also obvious. South-east of Ben Hiant summit, the margin of the intrusion is bordered by a scarp of baked older rocks comprising agglomerates, belonging to the two Ben Hiant vents, and the Porphyritic Dolerite plug (p. 150). Close-set vertical jointing has been developed in the rocks forming the scarp, so that the latter, at a distance, strikingly resembles a cross-jointed sill. Such jointing, arising in baked rocks at right angles to the margin of the intrusion concerned, has also been observed in the ring-dyke complexes (pp. 272 and 286).

Though the Ben Hiant Intrusion is later than all vent-materials, it nevertheless appears as if it were connected with the Ben Hiant vents. Its lateral expansion upwards in mushroom form, and the evidence supplied by its capping of variolite (p. 168), suggest that the magma filled the throat and crater of the volcano, and that its upper surface solidified under little if any cover. On the other hand, when we examine the evidence bearing on its age relations with the cone-sheets referred to Centre 1, there arises a strong probability that the intrusion of the dolerite took place during this cone-sheet period. This evidence has been already stated, but is briefly summarized below.

(1) In chemical composition the Ben Hiant dolerite is identical with quartz-dolerite forming cone-sheets (p. 82). In mineralogical composition it differs from the majority of cone-sheets. It is, however, similar to at least one cone-sheet (24468) which is situated, like the Ben Hiant dolerite mass, towards the exterior of the cone-sheet belt referred to Centre 1.

(2) On the north-eastern side of the Ben Hiant Intrusion apophyses from it are injected along inclined fractures that follow the same trend and direction of inclination as adjacent cone-sheets.

(3) The Ben Hiant Intrusion is cut by one cone-sheet, and accordingly must be earlier than some part of the cone-sheet period. The cone-sheet concerned penetrates for a short distance the outlier of Ben Hiant dolerite forming Stallachan Dubha (Fig. 10). Though no typical cone-sheets are intruded into the main mass of the Ben Hiant Intrusion, the presence of cone-sheet fractures, unfilled by magma, seems to be indicated by the erosion-featuring of the mass (p. 160). Possibly an intrusion of the Ben Hiant magma into such a fissure is represented by an inclined sheet with ill-defined edges which traverses the dolerite on the north-west slope of Ben Hiant. The sheet-rock is a very fine-textured dolerite of Ben Hiant type (26108). Since it is not contact altered it cannot be xenolithic, and it must therefore be intrusive in relation to the main mass.

VARIOLITE

On the Memoir-map the variolite (lettered qD′) has been separated from the doleritic portion of the Ben Hiant Intrusion. As its occurrence is of considerable interest the mass is described in detail.

In the hand-specimen the typical variolite is black and sub-vitreous. Such rocks are seen in the field to pass gradually downwards, by increase in number and size of crystals, into normal Ben Hiant dolerite. The outcrop covers a narrow area on the upper slopes of the mountain, west-south-west of the summit (Fig. 10, p. 122). For the most part the variolite forms a comparatively thin layer over the dolerite, and it nowhere extends in depth like a dyke. The elongate shape of the outcrop down the hillside appears to be partly the effect of downthrow along two north-west crush-lines that cross the outcrop; the higher portions of the outcrop, however, east of the more westerly crush-line, con-

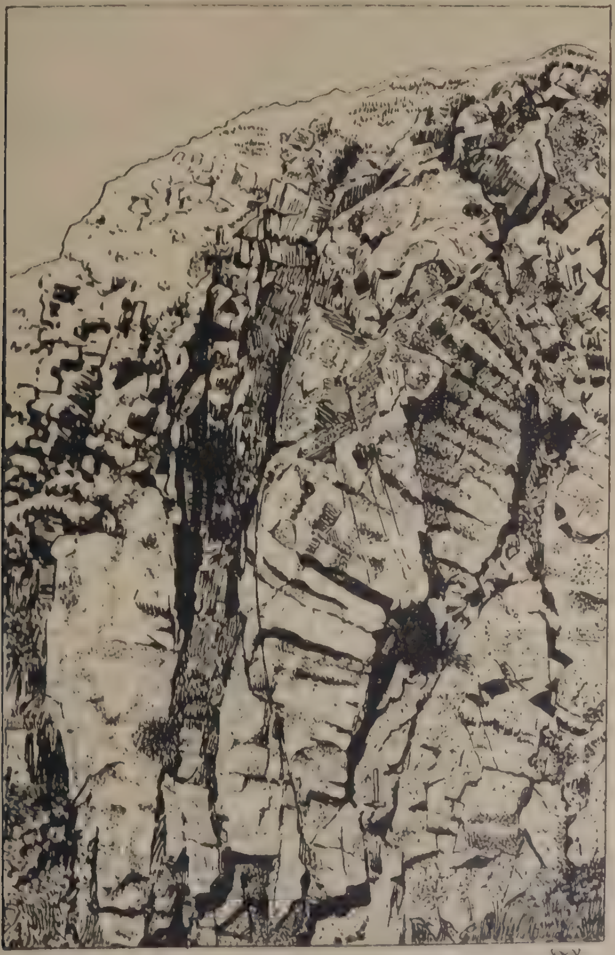

Fig 21..—*Twenty-foot cliff of columnar variolite (part of Ben Hiant Intrusion), traversed by crush-line, south-west side of Ben Hiant.*

Drawn from Geological Survey Photograph No. C. 2852.

tribute to the effect by being inclined slightly downhill towards the west. West of this crush-line the variolite forms a flat capping at the top of steep slopes above the dyke-like portion of the Ben Hiant Intrusion. Along the top of the capping small vesicles are developed in the variolite. This capping is exposed in section along a stream, on the north side of which it forms a 20-ft. cliff (Fig. 21). The variolite is there prismatically jointed, with narrow six-sided columns inclined gently to north-north-east. In the underlying dolerite the more widely spaced vertical jointing that is characteristic of the Ben Hiant Intrusion is developed. The hexagonal columns of variolite are of much smaller diameter than those already described from a basal portion of the Ben Hiant Intrusion (p. 161). There is thus similarity between the columnar structures developed in the Ben Hiant mass and those of the pitchstone lavas of the South-west Vent (p. 128).

The gradation downwards of variolite into dolerite is well seen in the cliff-section above mentioned. Towards the base of the cliff, small scattered felspar crystals make their appearance. These increase gradually in the downward direction both in size and abundance, and form crystal-groups. At a slightly lower level the groups coalesce into a delicate crystal network with meshes of variolite. Finally, variolite becomes further reduced in amount and occurs as streaks and patches in a doleritic rock. The conclusion was reached in the field that the felspars had grown out of the variolite ground-mass, and this is confirmed by microscopic examination (p. 171).

The above evidence points to the variolite being a quickly cooled upper portion of the Ben Hiant Intrusion. The chief objections to this interpretation are, the inclined disposition of the layer of variolite on the upper slopes of Ben Hiant, and the narrowness of the outcrop. These difficulties, however, may not be of fundamental importance. It is not impossible to imagine a vent-infilling, consolidated beneath its own quickly cooled crust, having a concave upper surface: and of this crust the variolite seen may be a remnant. Similarly, if narrowness of outcrop cannot be regarded as due merely to the chances of denudation, it may be surmised that a first-formed crust of variolite was broken through during a renewed upward movement of magma, and that a portion north of the elongate outcrop now seen became displaced.

Other occurrences of variolite in connexion with the Ben Hiant Intrusion are as follows. Along the south-east margin, the baked older rocks in contact with the Ben Hiant dolerite are penetrated by thin veins of variolite, evidently derived from the margin of the intrusion, though their actual continuity has not been proved. Again, thin sheets of variolite occur here and there in the dolerite, and are probably auto-intrusions of the dolerite magma. Good examples traverse a scarp of dolerite that overlooks Camas na Cloiche Mòire bay, some 450 ft. above sea-level. These variolite sheets have thin selvages of glass (21452), and they seem to lend support to the conclusion already arrived at that the Ben Hiant dolerite magma when quickly cooled solidified as variolite.

XENOLITHS

The Ben Hiant dolerite contains in certain places a considerable amount of xenolithic material. At various localities in the hollow north of the summit, and in the long tongue projecting from there towards Loch Mudle, xenoliths of schist are very abundant. The fragments are angular and crowded together in a matrix of dolerite, or occur more sparsely in all stages of resorption (21456, 22456). Interesting changes in the dolerite are thus produced.

Another locality where xenoliths are plentiful is on the coast, about 150 yds. north-west of the south-east margin of the intrusion. A number of small basic xenoliths occur, but large elongate blocks of big-felspar basalt up to 8 yds. long are especially conspicuous. The dolerite is either in sharp contact with these large xenoliths or appears to be corroding their margins, enclosing the large felspars as xenocrysts. Acid veins traverse both dolerite and xenoliths. The xenoliths were presumably derived from the adjoining agglomerates, in which large blocks of big-felspar basalt are of common occurrence.

A still larger mass of porphyritic basalt, probably xenolithic, outcrops alongside a stream three quarters of a mile west of the summit of Ben Hiant. It is some 50 yds. long by 20 yds. in breadth, but no contacts with dolerite are seen. J.E.R.

PETROLOGY OF BEN HIANT INTRUSION

(Anal. II, Table II, p. 82)

Normal Types.—The Ben Hiant mass is a somewhat variable but very beautiful quartz-dolerite. Its structure is that of a non-porphyritic ophitic dolerite having a varying amount of microcrystalline and semi-glassy mesostatic matter. Its most important crystalline components are olivine, aluminous augite, labradorite felspar, and ilmenite. The base is composed of acid plagioclase and alkali-felspar in skeletal growths, quartz, acicular augite, a little finely divided iron-ore, somewhat abundant apatite, and glass. The olivine is a pale optically positive variety moderately rich in iron, but well removed from the fayalite end of the series. Frequently it is quite fresh (21449, 22296) or only partly decomposed. Occasionally it builds well-shaped crystals, but more commonly it is quite irregular in form. It was an early product of consolidation but it was not always earlier than felspar, for some lath-shaped crystals of basic plagioclase are frequently enclosed by it in an ophitic fashion. The augite encloses it and the early felspars indiscriminately. In some examples (22453, 21253) it is represented by pseudomorphs, and quite commonly it is replaced by a dull green substance, with low refractive index and birefringence, referable to chlorophæite (21253, 22450).

The augite is a normal aluminous variety containing possibly a small amount of titanium, but the lilac tint indicative of a high titanium content is wanting. The colour is pale greenish-brown in thin section and there is no pronounced pleochroism. In many dolerites where augite is in contact with a siliceous and alkaline mesostasis, it is fringed with a narrow layer of green colour indicating the presence of the alkaline molecule, but this has not been noticed in the case of the Ben Hiant quartz-dolerite.

The felspars are small, twinned, and somewhat irregularly rounded lath-shaped crystals of labradorite, which seldom if ever show a porphyritic tendency. They are usually zoned by increasingly acid varieties culminating in oligoclase, and, as might be expected, these crystals present rather indefinite boundaries to the mesostasis when they are in contact with it. The mesostasis is a very interesting and important part of the rock. It is variable both as regards quantity and distribution, and the variation appears to be related to the structure of the more coarsely crystalline portions of the rock. Where the amount of mesostasis is small or segregated into lakes (21449, 21454), the rock has a well-marked ophitic structure, but where the distribution is more general and the amount greater (22453, 22454), the rock has a finer texture and a tendency to assume a glomero-porphyritic structure. The mesostasis itself consists largely of alkali-felspar and quartz. The felspar exists chiefly as skeletal growths of orthoclase with some albite, and to some extent is an obvious product of the devitrification of an alkaline glass. It also forms feathery growths with quartz (22450), and merges insensibly into a residual pale-brown glass (22454). The mesostasis invariably carries acicular crystals of augite, sometimes of minute dimensions. The larger crystals of augite are columnar in habit and are studded with magnetite

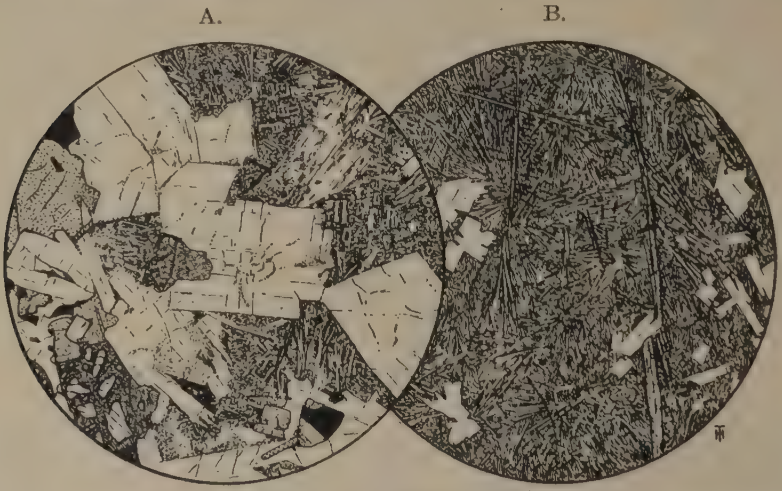

FIG. 22.—*Ben Hiant Intrusion.*

A. (22296) × 20. *Quartz-dolerite. The section shows partly decomposed olivine, labradorite felspar, augite, and ilmenite in a matrix of skeletal felspars, acicular augite, quartz and iron-ore.*

B. (24235) × 20. *Variolite. Small phenocrysts of labradorite felspar in a base consisting of blade-like crystals of yellowish-brown augite, long rods of magnetite, and a fine feathery crystallization of oligoclase-andesine felspar.*

along their margins (22453), after the manner of the columnar augites of the quartz-dolerites of Mull.[1]

One of the most striking features of the mesostasis is the great concentration of apatite which has been effected within it and which shows as abundant slender crystals of this mineral. A similar concentration of apatite in a residual partial magma is a more or less constant feature of the quartz-dolerites, and was discussed in connexion with rocks of this class in Mull.[2] Although differing in certain respects from the bulk of the cone-sheets (p. 159), the Ben Hiant quartz-dolerite is clearly a representative of the same magma-type. It will be seen from a comparison of analyses (p. 82), that the average cone-sheet and the Ben Hiant quartz-dolerite are for all practical purposes of identical composition, and thus the rocks must be regarded as having been furnished by the same magma, or by similar magmas that had reached the same stage in their respective courses of differentiation. Further, it is quite clear that the Ben Hiant Intrusion is representative of a moderately basic phase of the Normal Magma-Series (Fig. 6, p. 80).

Variolite.—A portion of the Ben Hiant mass, possibly a rapidly chilled part of the intrusion, is an aphanitic rock with a most beautifully developed variolitic structure (Fig. 22, B.). The bulk of this variolite when examined microscopically exhibits a structure that is practically identical with that of the variolitic cone-sheets of Cruachan Dearg in Mull.[3] In its most completely variolitic development, in the flat capping mentioned above, it is of uniform texture in the hand-specimen. It shows, however, small glomero-porphyritic groups of augite and felspar which become increasingly numerous and more coarsely crystalline as the normal quartz-dolerite is approached.

Microscopically, the variolite (22451, 24235) consists of slender blade-like crystals of yellowish-brown augite, elongated parallel to the *c* axis, long rods of magnetite which often connect transversely the augite blades, and a fine feathery growth of oligoclase-andesine felspar in the form of slender skeletal crystals frequently with forked terminations and glass inclusions. As noted in the case of the variolites of Cruachan Dearg in Mull, the felspar occasionally aids in determining the variolitic structure, but more frequently forms radial or feathery groups that have no definite relation to the disposition of the early augites. In this part of the matrix, however, we may note an approach to the cervicorn structure so characteristically developed in certain of the cone-sheets of Mull.[4]

The variolite contains a few small glomero-porphyritic groups of brownish aluminous augite and labradorite felspar, also isolated felspars of similar composition. The augite is subophitic with respect to felspar, but hypidiomorphic towards the variolitic base. The felspars when in contact with the variolitic matrix generally have long skeletal outgrowths, and show other signs of rapid growth under conditions of chilling.

The passage from variolite to quartz-dolerite is illustrated by a suite of specially collected specimens. Proceeding downwards towards the normal quartz-dolerite the variolite becomes more obviously crystalline through the greater abundance of glomero-porphyritic patches and the relative subordination of the variolitic matrix (24236). The same mineralogical and structural features obtain, however, and the observed differences, at any rate for some distance, are merely of degree. The individuals comprising the crystal groups are now of larger dimensions, and the augite is more coarsely ophitic. The variolitic structure of the matrix, as outlined by blade-like augite and rods of magnetite, becomes somewhat less definite, and the place of much of the blade-like augite appears to be taken by thicker and less frequent columnar crystals that are intimately associated with magnetite (24237). At the same time the ultimate felspathic base, while still retaining a feathery intersertal crystalline texture, becomes more alkaline in character, and shows a tendency to approximate to the composition of the normal mesostasis of the quartz-dolerite and to separate free quartz. Olivine also begins to make an appearance, chiefly as small crystals in the matrix (24237). The rod structure of the magnetite still persists. Still nearer the normal quartz-dolerite the matrix is more reduced in bulk. It no longer has a true variolitic structure, but exhibits an abundance of skeletal growths of acid plagioclase felspar and plentiful magnetite in a brownish glass that yields quartz as a product of devitrification. Semi-columnar crystals of augite are of frequent occurrence in an unaltered condition, but traversing the same glassy matrix are deep yellowish-brown platy pseudomorphs which I regard as representing fayalite (24239). The crystallization of fayalite from siliceous melts is well known, both in natural and artificial processes, and from the habit and nature of the pseudomorphs it would appear to have been the ferrosilicate that crystallized in the acid base of the rock under description. The glomero-porphyritic grouping of the more basic plagioclase and ophitic augite is the dominant feature of the mass as it approaches the quartz-dolerite type, but there is also a more marked tendency to a columnar crystallization of augite in the matrix. The mesostasis still retains a subvariolitic structure, but this is outlined by what I consider to have been fayalite rather than by augite as was the case in the more basic and more rapidly chilled variolites.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 302.

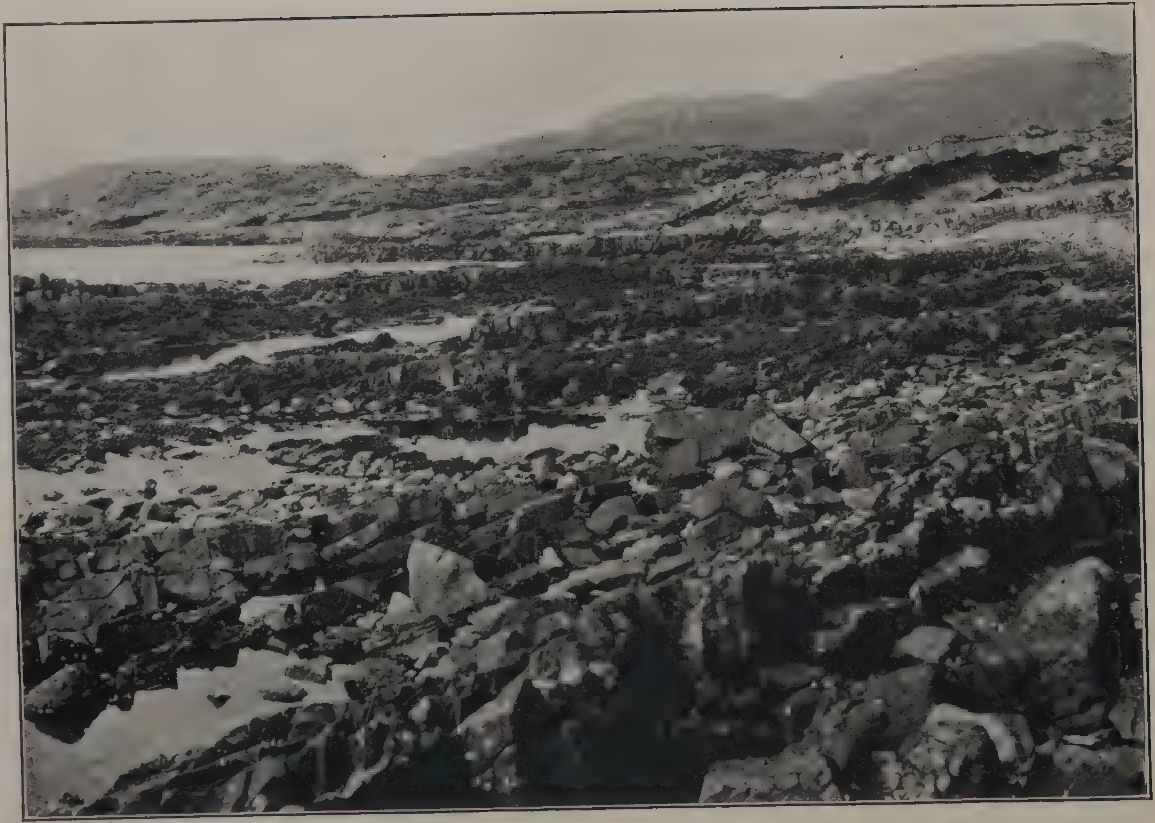
[2] *Ibid.*, p. 329.

[3] *Ibid.*, pp. 304–305.

[4] *Ibid.*, pp. 302–303.

To sum up the gradual changes from the true variolite to the normal quartz-dolerite, there appears to be a thick variolitic portion, which gives place in a distance of a few feet to the normal type by a gradual increase in the coarser crystalline elements, accompanied by a steady but slight increase in the siliceous character of the residuum. This gradual change in the composition and bulk of the residuum is accompanied by a gradual suppression of the true variolitic, in favour of a skeletal, type of crystallization and a development of fayalite. A marked tendency to the development of variolitic structure is also exhibited by certain glassy auto-intrusive sheets (21452) (p. 168) that occur within the Ben Hiant main intrusion. H.H.T.

PLATE IV.



Quartz-dolerite Cone-sheets along Shore south of Kilchoan, Ardnamurchan.
(For Explanation, *see* p. viii.)

CHAPTER XIV

TERTIARY CONE-SHEETS, CENTRES 1, 2, AND 3, ARDNAMURCHAN

THE importance of cone-sheets in the igneous geology of Ardnamurchan will be realized from an inspection of the coloured Memoir-map, where, together with subordinate sills, they are indicated by the letter I. On one-inch Sheet 51 the same letter is further employed to denote certain basic inclined sheets of North-west Mull. The latter are probably connected with the Ardnamurchan igneous focus, but since they differ from the cone-sheets in direction they are described separately (Chap. XXII).

The majority of the cone-sheets are individually quite thin, but they occur in vast numbers, and may collectively form extensive outcrops. For the most part they are indicated diagrammatically on the small-scale published maps, and also on the ordinary field-maps (scale 6 inches to the mile). A well-exposed shore-section south of Kilchoan mapped on a larger scale (25·344 inches to the mile) is reproduced in Fig. 23. This map and the accompanying horizontal section serve to illustrate the great abundance of the cone-sheets, their almost uniform inclination and strike at any particular locality, their transgressive relation to the bedded rocks, and their occasional offshoots along the bedding planes as sills.

The cone-sheets are chiefly composed of non-porphyritic quartz-dolerite of Talaidh type, or of porphyritic basalt. Composite cone-sheets and sills also occur here and there, with margins of quartz-dolerite and more acid centres of craignurite, granophyre, or felsite. In the chilled edges and fine-grained marginal zones of the porphyritic cone-sheets, felspar phenocrysts are frequently not developed.

Various sets of cone-sheets can be distinguished, but only portions of them are now on view owing to their partial replacement by ring-dykes, and to the fact that much of their outcrop is hidden by the sea. The visible portions suffice to show that cone-sheets were developed around each of the three Intrusion-Centres of Ardnamurchan (*see* Pl. II, p. 71). An eastern set of massive individuals conforms to the same Centre 1 as the Northern Vents and the Early Major Intrusions. Two sets are arranged around Centre 2, an Outer Set earlier than all ring-dykes, and an Inner Set that is later than the majority of the ring-dykes of Centre 2. Lastly, a few basic inclined sheets cut the outermost and earliest ring-dyke of Centre 3, the Quartz-gabbro (A), and are inclined towards this centre. These are regarded as a partially developed set of cone-sheets.

Individual cone-sheets that make up each set were intruded successively, for they bear well-chilled margins whether in contact with country rock or with an earlier cone-sheet. Successive in-

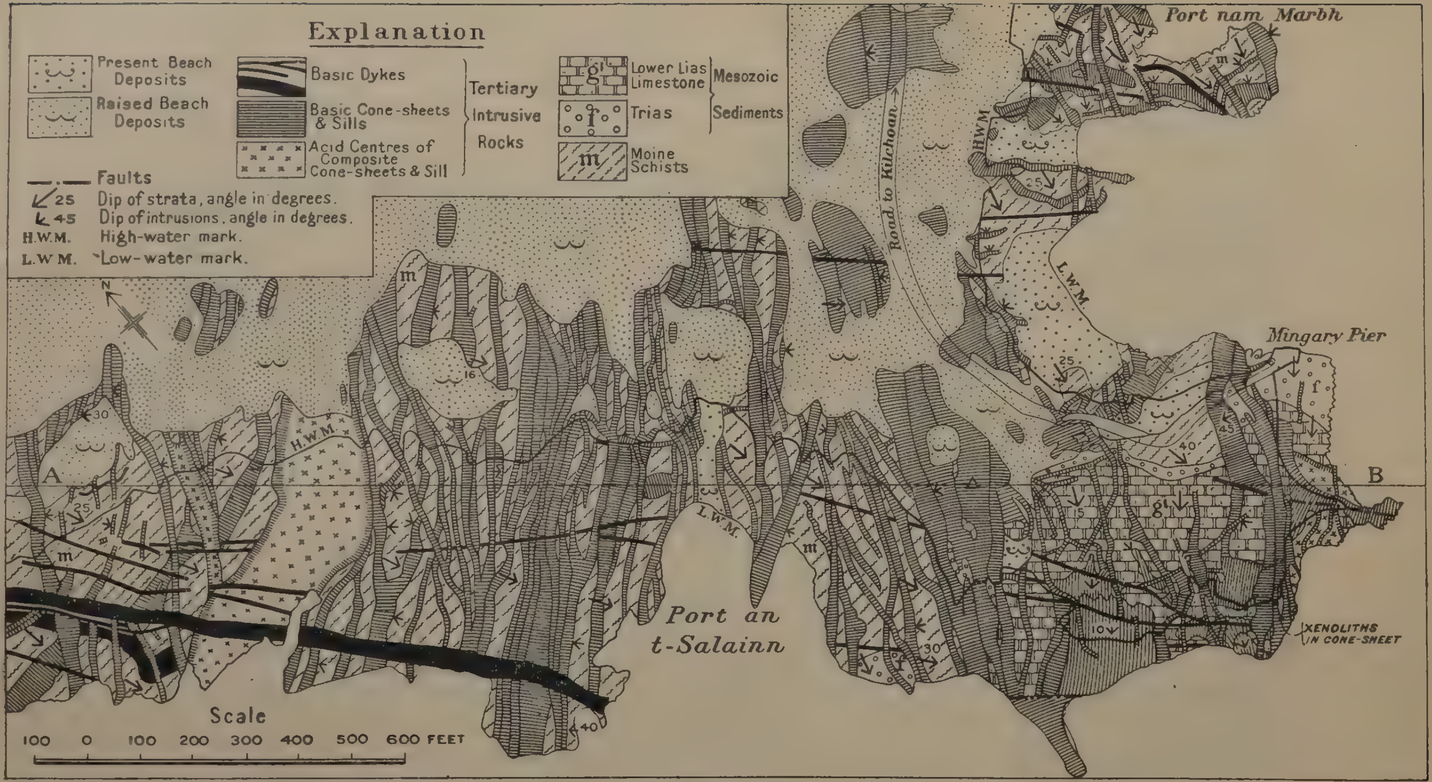

Explanation
Present Beach Deposits
Raised Beach Deposits
Basic Dykes
Basic Cone-sheets & Sills
Acid Centres of Composite Cone-sheets & Sill
Tertiary Intrusive Rocks
Lower Lias Limestone
Trias
Mesozoic Sediments
Moine Schists
Faults
25 Dip of strata, angle in degrees.
45 Dip of intrusions, angle in degrees.
H.W.M. High-water mark.
L.W.M. Low-water mark.
Port nam Marbh
Road to Kilchoan
HWM
L.W.M.
Mingary Pier
N
A
B
Port an t-Salainn
XENOLITHS IN CONE-SHEET
Scale
100 0 100 200 300 400 500 600 FEET

FIG. 23.—*Map of Outer Cone-sheets of Centre 2, shore south of Kilchoan.*

trusion is also indicated by the fact that the same north-west dyke may cut and also be cut by cone-sheets (Figs. 23 and 25)

The basic cone-sheets are, as a rule, conspicuously cross-jointed (*see* Pl. IV). Rarely, they weather spheroidally. Only five instances of this were noted, for example, along the coast-section illustrated in Fig. 23. A cone-sheet showing both spheroidal weathering and cross-jointing may be cited from the southern corner of the Mingary Pier headland (Rudha Àird an Iasgaich), 150 yds. south-west of the Pier. The intrusion is about 21 ft. in thickness, and consists of spheroidally weathering margins, 6 ft. thick, and a central cross-jointed portion. The junction of the different portions is well defined, and though there is no sign of an intrusive contact it seems probable that there were two injections of magma, quickly following one upon the other. A third injection is perhaps represented by an elongate mass of extremely xenolithic quartz-dolerite, full of schist fragments, which extends along the centre of the middle cross-jointed portion of the cone-sheet for 20 yds. (*see* p. 190).

The inclination of the cone-sheets varies within wide limits, though the variation within any particular set is small. Those of Centre 1 dip at low angles, on an average at about 20 degrees. In the Outer Set of Centre 2 angles of 35 to 45 degrees are met with, the lower angles being the more usual. Those of the Inner Set of Centre 2 are inclined very uniformly at an angle of 70 degrees. Those of the partially developed set of Centre 3 are inclined at 50 degrees.

Various data concerning the Ardnamurchan cone-sheets are set out in tabular form below.

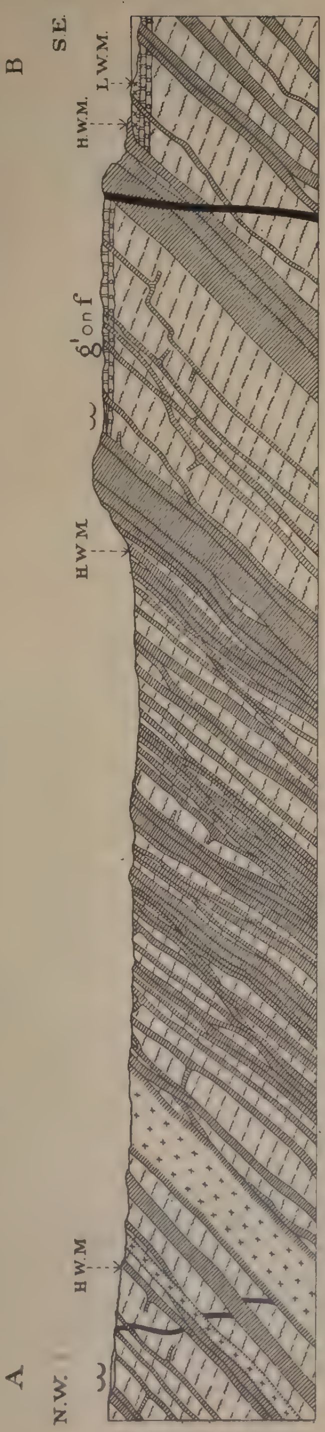


FIG. 24.—*Section along line A–B of Fig. 23.*

TABLE VI

DATA CONCERNING CONE-SHEETS, ARDNAMURCHAN

Order of Age.	Title of Set.	Angle of Inclination.	Thickness in Feet.	Age Relations with Other Intrusions.
1	Set of Centre 1	10–20°	20–50	Pene-contemporaneous with Ben Hiant Intrusion, and later than Ben Hiant and Northern Vents.
2	Outer Set of Centre 2	35–45°	5–20	Later than the Major Intrusions of Centre 1, generally. Almost all earlier than all ring-dykes.
3	Inner Set of Centre 2	70°	5–30	Later than most ring-dykes of Centre 2. Earlier than all ring-dykes of Centre 3.
4	Partial Set of Centre 3	50°	3–5	Later than earliest of the ring-dykes of Centre 3, and earlier than Great Eucrite Ring-dyke.

The phenomenon of cone-sheet injection is obviously connected with localized crustal stresses, and these are considered to have been produced in the roof of a restricted magma-reservoir (p. 78 and Fig. 5, p. 57). In Ardnamurchan the regional N.E.–S.W. crustal tensions, so characteristic of the British Tertiary igneous period, and which find expression in north-west dykes and crush-lines, may have operated within the area affected by the local cone-sheet tensional stresses and contemporaneously with these stresses. This would account for a tendency to north-west trend shown by individual cone-sheets mapped by Messrs. Bailey and Simpson along the outer, eastern limit of the massive cone-sheets of Centre 1 (*see* Memoir-map). Again, in the case of the Outer Set of Centre 2 north-north-east of Camphouse, cone-sheets forming a group about half a mile wide follow a north-west course and are considerably out of line with their neighbours that run with reference to the same centre. In this connexion a further point of interest is the occurrence of north-west dykes of the same composition and age as the cone-sheets (p. 348).

The combined effect of the injection of such immense numbers of cone-sheets as are found in Ardnamurchan must have been attended with considerable central uplift. In the case of the Outer Cone-sheets of Centre 2, our knowledge seems sufficiently complete to allow us to form an estimate of the probable amount of the vertical displacement. In our calculation two assumptions are made. In the first place, it is postulated that space for each cone-sheet injection was provided by displacement of its roof, not

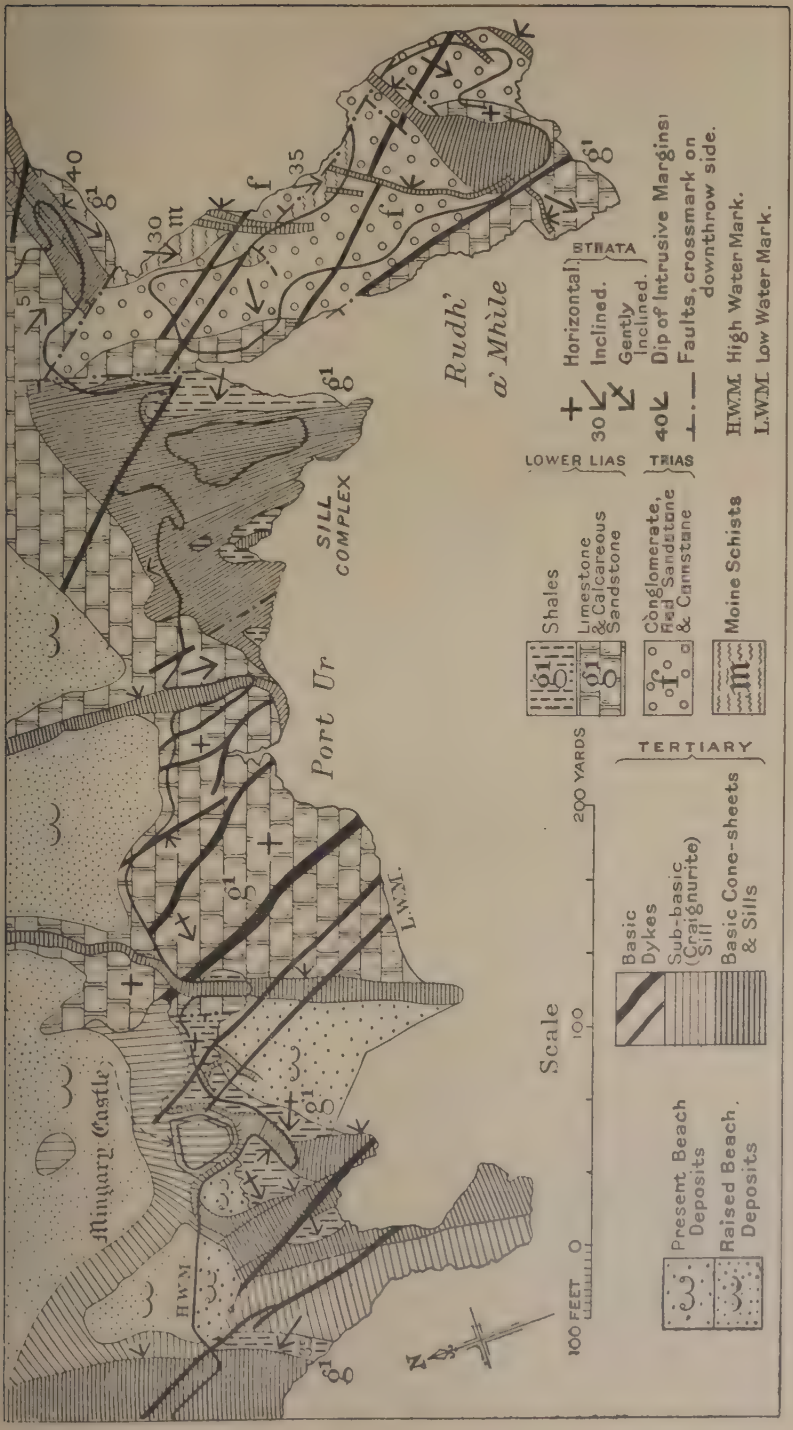

Mingary Castle
Port Ur
Rudh' a' Mhile
SILL COMPLEX
HWM
L.W.M.
g¹
f
m
30
35
40
5
N
Scale
100 FEET 0 100 200 YARDS
Present Beach Deposits
Raised Beach Deposits
TERTIARY
Basic Dykes
Sub-basic (Craignurite) Sill
Basic Cone-sheets & Sills
LOWER LIAS
Shales
Limestone & Calcareous Sandstone
TRIAS
Conglomerate, Red Sandstone & Cornstone
Moine Schists
STRATA
Horizontal
30 Inclined
Gently Inclined
40 Dip of Intrusive Margins
Faults, crossmark on downthrow side.
H.W.M. High Water Mark.
L.W.M. Low Water Mark.

FIG. 25.—*Map of shore near Mingary Castle, east-south-east of Kilchoan.*

of its floor. Further, it is only on the south-east side of the cone-sheet belt that we can form an estimate of the aggregate thicknesses of the Outer Cone-sheets. Elsewhere the belt is only partly seen, and we have to assume that cone-sheet intrusion was, in the aggregate, more or less equal around the whole belt. With these assumptions the uplift of the central area enclosed by the belt of Outer Cone-sheets may be calculated by the equation $x = y/\cos a$ where x = total uplift due to the whole belt, y = aggregate thicknesses of cone-sheets forming the belt, and a = average angle of inclination of the cone-sheets.

Now the belt of Outer Cone-sheets on its south-east side is about 2 miles in width. Towards its inner and outer margins the number of cone-sheets diminishes. An average density of intrusion for the central three fourths of the belt is considered to be presented by the shore-section south of Kilchoan, which has been accurately mapped (Fig. 23), while an average for the remaining fourth may be taken as half of this amount. The combined thicknesses of the cone-sheets in the half-mile section of Fig. 23 are approximately 950 ft. The total for the whole belt may then be estimated at about 3300 ft. Taking the average inclination of the cone-sheets to be as low as 35 degrees, we obtain 4000 ft. as an estimate of the total uplift.

It is of interest to note that doming of the country rocks around Centre 2, developed within the limits of the belt of Outer Cone-sheets, seems to have immediately preceded the injection of these cone-sheets (p. 116). The doming may, therefore, have been occasioned by the same magma-pressure as that which determined the cone fissures and injection of cone-sheet magma.

However approximate an estimate of total uplift due to cone-sheet intrusion may be, it seems at least evident that at various periods central parts of the Ardnamurchan area must have experienced considerable uplift. Such uplifts during times of increased pressure in the magma-reservoir may, however, have been compensated by later subsidences that accompanied ring-dyke intrusion when magma-pressure became reduced.

DETAILED DISTRIBUTION

Cone-sheets of Centre 1.—These easterly cone-sheets have been mapped by Messrs. Bailey and Simpson from the northern coast, between Achateny and Ockle, as far south as Loch Mudle, and by the writer farther south. The individuals are generally massive and give rise to well-defined scarps. An especially prominent example forms the summit of Beinn nan Losgann. The trend of the sheets, considered as a whole, refers them definitely to Centre 1.

West of Ben Hiant, towards Kilchoan, these early cone-sheets have not been recognized with certainty. There, cone-sheets conforming to Centre 2 are extremely abundant, but in the mapping of this very complicated belt of country some occurrences of basic cone-sheets inclined towards Centre 1 were recorded, and may belong to the early set. For example, along the shore eastwards of Mingary

Castle, cone-sheets follow two directions, east-north-east and north-north-east. The east-north-east cone-sheets dip towards Centre 1, while those running north-north-east incline towards Centre 2, but evidence of their relative ages was not obtained. Between Mingary and the summit of Glas Bheinn to the north, there is also a very complex area of cone-sheet intrusion, and it would be of interest to know if cone-sheets referable to Centre 1 could be identified there. Only those following the north-north-east direction were noted during the mapping, but older quartz-dolerite was also observed, the decipherment of which was not attempted. Farther west, on the west side of Kilchoan Bay, two massive intrusions of quartz-dolerite extending north-west may belong to Centre 1. They at any rate are of early date, as they are cut by the Outer Cone-sheets of Centre 2. One of them forms a slight headland a mile south-west of the Landing Jetty, the other a projecting point of the headland of Sròn Bheag. The latter is lettered eD on the geological maps, and can be traced for a quarter of a mile. It is accompanied on either side by granophyre intrusions that are found both in sharp and in merging contact with it. The mass is in the nature of a composite intrusion, and will be described later in detail (p. 197).

Outer Cone-sheets of Centre 2. A belt of country very sparsely cut by cone-sheets extends from Achateny past Brachouse southwards towards Camphouse, and separates the massive cone-sheets of Centre 1 from the Outer Set of Centre 2. The Centre 1 sheets here fall outside, that is to the east of, the Centre 2 sheets. For each set, the outer limit of sheet distribution lies at about 4½ miles from the centre concerned.

Internally, the belt of Outer Cone-sheets belonging to Centre 2 is limited by the succeeding ring-dyke complexes, but in one area west of Kilchoan, next to the ring-dykes of Centre 2, the cone-sheets become sparse before this limit is reached. The outer margin of the ring-dykes thus appears, here, to be approximately at the original inner limit of the sheet belt, at a distance of 2 miles from Centre 2. As will be seen on the Memoir map only a portion of the belt is on view, but this remnant seems sufficient to show that the belt originally completely encircled the Centre.

The Outer Cone-sheets of Centre 2 are so thin and abundant that they are represented diagrammatically on the published geological maps. They are shown individually on Figs. 23, 24, and 25. Along the shore south of Kilchoan (Fig. 23), their field relations may be conveniently studied. Above high-water mark, 200 yds. west of Mingary Pier, cone-sheet fracture planes unfilled by magma are well seen in Lower Lias limestone. The beds of limestone with partings of shale of varying thickness can be followed by the eye across the fractures, showing that there has been no displacement along them. Where the fractures are filled by magma, such displacement of the walls as is found seems to be only so much as is necessitated by the thickness of the intrusion. For example, in the horizontal section, Fig. 24, a group of three thick cone-sheets, south-west of Mingary Pier, crosses the outcrop of the Trias and appears to shift it no more than the combined thicknesses of the cone-sheets require.

In a low-water promontory north of the Pier, sills in the Moine Schists are invariably cut by the cone-sheets. No visible cone-sheet feeders for the sills are there seen, but, along the shore north-west of the Pier, sills and cone-sheets in continuity with one another are on view. There is no reason to suppose that the sills form a separate group from the cone-sheets. In composition both are quartz-dolerites, though the sills are usually of finer texture, a difference which is irrespective of thickness. Sills greatly complicate the network of Outer Cone-sheets north of Kilchoan on the south side of Glas Bheinn. Possibly also, as already mentioned, cone-sheets of Centre 1 may occur here.

West of Kilchoan above Ormsaigbeg the hill-slopes are featured by regularly running cone-sheets that are rather gently inclined. Porphyritic types become frequent here, towards the inner limit of the belt, and are the dominant type farther west, south of Beinn nan Codhan. Along the coastal cliffs westwards of Sròn Bheag, which are mainly formed of Jurassic limestone and sandstone, a plexus of dark sheets (cone-sheets and sills) traverses these white-weathering beds. The cliffs are conspicuous from the seaward side, and attracted the attention of Macculloch (p. 65), and later of Sir A. Geikie,[1] both of whom have illustrated them by drawings.

Westwards of Beinn nan Codhan, and north-west of An Acairseid, two highly baked screen-like masses of Lower Lias shales and Tertiary basalt lava partly separate the main mass of the Hypersthene-gabbro Ring-dyke from an outer arm that forms the ridge of Garbhlach Mhòr. The strike of the cone sheets has here swung round to the north-west. Cone-sheets and country rock are so highly altered that their separation in the field is a difficult matter, but the brown-weathering surfaces of the cone-sheets and the greyer hues of the Lias shales and Tertiary basalt lava serve to distinguish them.

Northwards of Garbhlach Mhòr to Sanna Point the Outer Cone-sheet Complex lies out to sea except for a single cone-sheet cutting the Hypersthene-gabbro at the Point of Ardnamurchan, which may perhaps be regarded as a late representative of the Outer Set (*see* p. 183). East of Sanna Point, the cone-sheet complex again comes ashore, but is so highly baked by the adjoining Hypersthene-gabbro that the direction of its component sheets can only be determined with difficulty. That we are here dealing with a cone-sheet complex referable to Centre 2 is, however, evident, for contiguous sheets are frequently separated by lenticles of the country rocks (Jurassic sandstone and limestone). Farther east, bordering the northern coast to the north of the Great Eucrite Ring-dyke of Centre 3, the cone-sheet complex is once more well seen, though adjacent to the Great Eucrite its component intrusions are as difficult to recognize individually as near Sanna Point. The cone-sheet belt is exposed continuously, in part at least, from this district round to the eastern side of the complex. An encircling belt of Outer Cone-sheets is therefore demonstrable except for the gap to the west where exposure is interrupted by the sea.

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[1] Sir A. Geikie, 'The Ancient Volcanoes of Great Britain,' vol. ii., 1897, **Fig. 248, p. 155.**

Inner Cone-sheets of Centre 2.—These cone-sheets will be seen on the geological maps to form a belt less than a mile wide traversing many of the Ring-dykes of Centre 2. The belt extends round a quarter of a circle only, being truncated to north and east by ring-dykes of later date. The outer limit of the belt on the south side is separated by a zone of older rock free of cone-sheets (the Hypersthene-gabbro) from the Outer Cone-sheets above described. Partly on this account the Inner Cone-sheets are held to constitute a separate set. In age also the two sets must differ, for the Outer Cone-sheets are contact altered close to the outer margin of the outermost ring-dyke (the Hypersthene-gabbro), whereas this intrusion near its inner edge is freely cut by the Inner Cone-sheets. Other points of difference between the two sets are the greater steepness of the Inner Cone-sheets, and their reference to a centre near Aodann slightly different to that of the Outer Set. The difference in inclination is a remarkable feature. The high dip of 65–70 degrees of the Inner Cone-sheets is met with across the whole belt, while within half a mile to the south the Outer Cone-sheets are inclined at much lower angles. Mr. E. M. Anderson[1] has formulated a theory of cone-sheet intrusion which accounts for interior cone-sheets being steep because of their position more directly above an intrusion-centre, but in the present case some additional factor would seem to be involved.

Partial Set of Cone-sheets of Centre 3.—North of Kilchoan, a few thin inclined sheets, chiefly of porphyritic basalt, traverse the outermost of the Ring-dykes of Centre 3 (Faskadale Quartz-gabbro), and isolated masses of basalt lava and agglomerate that occur within this ring-dyke complex. Their inclination is fairly constantly at an angle of 50 degrees, and is towards Centre 3. The breadth of the belt is three quarters of a mile, but individually the sheets have not been found to continue very far. They may be regarded as cone-sheets, but they constitute a very partially developed set.

Just south of the Ring-dykes of Centre 3, at the western extremity of Glas Bheinn, the Outer Cone-sheets of Centre 2 are abundant, and are non-porphyritic. A single porphyritic cone-sheet inclined towards Centre 3 was observed here cutting a non-porphyritic individual inclined towards Centre 2. West of this, on Glebe Hill, porphyritic types become more numerous, but some at any rate run tangentially to Centre 2, and it is evident that at this point porphyritic cone-sheets are becoming prevalent among the Outer Set.

A stray cone-sheet possibly belonging to the partial set traverses the Faskadale Quartz-gabbro Ring-dyke alongside a stream about half a mile north-east of Beinn na Seilg summit. It is composed of non-porphyritic basic rock, and is inclined towards Centre 3.

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[1] E. M. Anderson *in* 'Tertiary Mull Memoir,' 1924, p. 11.

AGE RELATIONS

Two lines of evidence are of service in determining the relative ages of the cone-sheets. In the first place, their distribution as described in the previous section shows that they occur as distinct sets. Secondly, the relation of the various sets to other intrusions, or groups of intrusions, fixes their relative positions in the igneous sequence. The more direct method of determining age, the traversing of one set of cone-sheets by members of another set, has not been found of much service in Ardnamurchan. It is difficult of application, owing to the similar composition of the sheets concerned at such crossing places, the great complexity of the cone-sheet assemblages, and the numerical insignificance of intrusions seen to cut one another, as compared with the sets to which they are referred. Age relations of the four sets to various other intrusions have been already stated in Table VI, p. 176, the evidence for which is given in detail below.

Cone-sheets of Centre 1.—These cone-sheets are demonstrably later than the Northern Vents. It is, however, noteworthy that quartz-dolerite fragments occur in the agglomerates, so that cone-sheet intrusion may also have preceded vent-formation, at some lower crustal level than that now exposed (*see* p. 131).

Their pene-contemporaneity with the Ben Hiant Intrusion has been already discussed (p. 166).

Outer Cone-sheets of Centre 2.—The prior age of this set to all ring-dykes follows from the evidence given below. The outer margin of the whole ring-dyke complex, against which the Outer Cone-sheets abut, will be described in clockwise direction, taking each ring-dyke concerned in the following order :—(1) Hypersthene-gabbro ; (2) Great Eucrite ; and (3) Quartz-gabbro of Faskadale. Of these, the Hypersthene-gabbro is perhaps the earliest of the Ring-dykes of Centre 2, while the other two intrusions are among the outermost and earlier members of the Ring-dykes of Centre 3 (*see* Pl. V, p. 201).

(1) Contact alteration of cone-sheets near to the Hypersthene-gabbro must be dated at any rate not later than this intrusion, the fine-grained outer margin of which is itself not contact altered. The effect is most pronounced in the case of the chilled edges of cone-sheets, which, when granulitized, lose their black, vitreous appearance and become stony. A good locality for observing this effect is on the hill-slope west-south-west of Kilchoan Free Church, near a track leading from Ormsaigbeg up to the twin lochs south-east of Beinn na Seilg. In this vicinity other evidence of age is the net-veining of cone-sheets and gabbro-margin alike with acid magma, marking a final stage in the crystallization of the ring-dyke. Farther west, where the outer margin of the gabbro meets the coast, south-west of Beinn nan Codhan, a good contact is seen against Lower Lias shales that are cut by a complex of cone-sheets and sills. Along this shore, just east of An Acairseid, the gabbro is intruded by three or four thin non-porphyritic cone-sheets, but on the other hand it truncates a great number of more massive,

porphyritic individuals that traverse the adjoining Lower Lias shales. There is therefore no doubt that the Hypersthene-gabbro is later than the porphyritic cone-sheets that are referred to the Outer Set of Centre 2.

Along the north margin of the Hypersthene-gabbro, highly contact-altered quartz-dolerite forms the headland east of Sanna Point, and includes lenticular patches of sediments (Jurassic sandstone and limestone). As already mentioned (p. 180), it is also possible to detect a few sheet-junctions in the quartz-dolerite, showing that the mass is a complex of cone-sheets, a continuation of the Outer Set. The contact alteration of the quartz-dolerite is evidently due to the Hypersthene-gabbro, which is in welded contact with it in a low sea-cliff west of the headland. On the other hand, on the north shore of Sanna Bay, the gabbro is cut by a thin basic cone-sheet inclined towards Centre 2, and farther east by a thick inclined-sheet of granophyre with similar dip and strike (*see* Memoir-map). Though the Outer Cone-sheets as a group are earlier than the Hypersthene-gabbro, there are about half a dozen cone-sheets, all except the granophyre quite thin, which cut its outer portion.

(2) The Great Eucrite is in contact with the Outer Cone-sheets for 2 miles on its north side, and has so completely granulitized them that their margins are very difficult to trace (p. 180). The effect decreases northwards away from the Eucrite, but, even along the northern coast east of Rudha Carrach, flakes of secondary biotite may be detected in the cone-sheets with a lens. J.E.R.

(3) Along the east and south-east sides of the ring-dyke complex, the Faskadale Quartz-gabbro comes into intrusive contact with many cone-sheets. Characteristic evidence of age is afforded by its highly-baked wall, composed in part of cone-sheets, which extends north and south parallel to the Allt Faskadale river. An actual contact of unaltered gabbro with granulitized cone-sheet rock is exposed where the gabbro reaches the coast, on the east side of Faskadale Bay (*see* p. 284). E.B.B.

Perhaps most striking of all is the evidence found on Glas Bheinn, north of Kilchoan. The outer margin of the Quartz-gabbro there transgresses the belt of Outer Cone-sheets for a distance of a mile, and runs almost at right angles to the direction of the cone-sheets. The north and south sides of the hill present a remarkable contrast. To the south, there are rugged rocky slopes formed of the cone-sheet complex, with a conspicuous massive cone-sheet extending obliquely up to the summit. To the north, smooth lower slopes are composed of quartz-gabbro, while a rocky, jagged crest is formed of an intensely baked complex of cone-sheets and country rocks.

Inner Cone-sheets of Centre 2.—These cone-sheets traverse practically all the Ring-dykes of Centre 2 excepting the Eucrite of Beinn nan Ord and the Quartz-gabbros of Loch Caorach and Beinn na Seilg (*see* Fig. 37). No contacts showing truncation of the cone-sheets by the margins of the Eucrite and Quartz-gabbros have been found, but the fact that two inwardly projecting lobes of the

Eucrite, at the north end of Beinn na Seilg and east of the north end of Beinn nan Ord, cross the strike of the cone-sheets and are not cut by a single individual, seems sufficiently to prove that the cone-sheets antedate the Eucrite. The Quartz-gabbros of Loch Caorach and Beinn na Seilg are apparently slightly later than the Eucrite, and are consequently to be regarded as later than the Inner Cone-sheets. Acid veining of a cone-sheet on the southern summit of Beinn na Seilg is perhaps due to the adjoining Quartz-gabbro.

The westward continuation of the Faskadale Quartz-gabbro north-north-east of Beinn na Seilg is intrusive in the Beinn nan Ord Eucrite, and also contact alters porphyritic cone-sheets of the Inner Set and an older Quartz-gabbro traversed by them (Fig. 28, p. 219).

Partial Set of Cone-sheets of Centre 3.—The Faskadale Quartz-gabbro north of Kilchoan is sparsely traversed by these cone-sheets, as is also the capping of basalt lava and agglomerate south-west of Meall an Tarmachain. In the latter locality the cone-sheets are contact altered next to the Great Eucrite, and the set would therefore seem to antedate this intrusion.

Composite Cone-sheets and Sills

These intrusions recur at intervals throughout the cone-sheet complexes of Centres 1 and 2. More striking examples from the British Tertiary province are already well known from Skye[1] and Mull,[2] and the Ardnamurchan occurrences need be only briefly described. They consist of basic, usually narrow, margins with more acid, thicker centres. The margins are of quartz-dolerite, the centres of craignurite, felsite, or granophyre. The contact between basic and acid portions may be either sharp or merging, or the two portions may be separated by a zone of intermediate composition which contains much altered and partly resorbed basic xenoliths. There is no doubt that the acid centres were intruded later, though not much later, than the basic margins. The basic margins are chilled externally against the country rock, but there is no chilling observable in the interiors of the composite sheets.

A good example of a composite sill is within easy reach of Kilchoan along the foreshore 60 yds. south of Mingary Pier (Fig. 23). Its lower portion is well seen, but its upper half has been cut out by a thick cone-sheet of later date and aberrant direction. A marginal basic, intermediate xenolithic and part of a central acid zone are on view. The basic margin, 1½ to 2 ft. thick, is in sharp contact with the intermediate zone. In the lower part of the latter, the xenoliths are frequently elongate, with rounded outlines and sharply defined margins. Higher up they become much smaller, and the rock is more acid. The central zone of felsite or granophyre is free of obvious xenoliths. Above the big aberrant cone-sheet, at the base of which this central portion ends, the lower part of the sill is again exposed. The junction between the intermediate and basic zones is here sharp at one place, but becomes ill-defined within a yard or so.

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[1] A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, pp. 197–234.

[2] E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 223.

Another good example of a composite sill is seen along the west side of Kilchoan Bay, just under a mile south-west of the Landing Jetty (*see* Fig. 3).

A composite cone-sheet with an unusually massive acid centre about 100 ft. thick, outcrops along the shore 600 yds. north-west of Mingary Pier (Fig. 23). No intermediate xenolithic portion is present.

Sometimes granophyre or craignurite occur alone, unaccompanied by a basic margin. As examples one may cite the granophyre cone-sheet north of Plocaig, and the craignurite sill on which Mingary Castle is built (Fig. 25). J.E.R.

PETROLOGY

The cone-sheets of Ardnamurchan, as of Mull, form a particularly interesting petrographical study, for they express definite and well-marked phases in the igneous history of the intrusive complex. In petrographical types they range over a wide scale from basic to acid, but sub-basic to intermediate types are most frequently encountered and certainly form the bulk of the cone-sheet intrusions.

In Mull the cone-sheets of successive intrusive periods, and co-ordinated to the different intrusive centres, showed remarkable constancy in their petrographical characters. The early sheets were mainly acid, followed by a great suite of olivine-dolerites. Later, with a shift of centre, came equally abundant quartz-dolerites. As has been discussed in the earlier part of this chapter (p. 182), in Ardnamurchan the greater number of cone-sheets were intruded before the larger plutonic masses reached their present position, and they are thus, relatively speaking, as early as, or earlier than, the bulk of the cone-sheets of Mull.

Amongst the cone-sheets of Ardnamurchan, non-porphyritic, variolitic, and porphyritic types are all represented. The majority of the porphyritic cone-sheets are more centrally situated and are, generally speaking, younger than their non-porphyritic associates. The cone-sheets thus present a sequence that corresponds to a definite time-change in magmatic composition.

The non-porphyritic types mainly have affinities with the quartz-dolerites, and with rare exceptions occur beyond the limits of the plutonic intrusions. Sheets that cut the plutonics and are definitely of later date, are mostly porphyritic dolerite with felspar phenocrysts. Comparable porphyritic basic cone-sheets occur in Mull. We have in Ardnamurchan, however, an apparent difference in the order of intrusion of the cone-sheets when compared with Mull; for whereas in Mull the quartz-dolerites and variolites were generally later than the porphyritic varieties, in Ardnamurchan quartz-dolerite appears to be the prevalent early type.

BASIC CONE-SHEETS BEYOND THE LIMITS OF THE PLUTONIC COMPLEX OF CENTRES 2 AND 3

Amongst these cone-sheets, variolitic, non-porphyritic, and porphyritic rocks are represented, and for purposes of description this order will be followed.

The Variolites.—The variolites of Ardnamurchan form a group subordinate to the general quartz-dolerite cone-sheets, and like the variolitic sheets of Cruachan Dearg in Mull[1] are fine-textured more or less tachylitic sheets of no great thickness.

As exemplified by a sheet referable to Centre 2, and exposed on the shore 100 yds. east of Rudha Groulin (21444), they consist of slender prismatic to acicular crystals of titaniferous augite and elongated narrow crystals of oligoclase-andesine felspar in a glassy partly devitrified matrix. The augite crystals, which reach 3 or 4 mm. in length, are traversed and occasionally linked together by numerous narrow plates and rods of magnetite, which are usually normal to, or make a wide angle with, the long axes of the pyroxenes.

The devitrification of the glassy base has largely resulted in the formation of feathery aggregates of felspar and quartz, the latter mineral frequently being segregated into small but easily recognized patches.

In this form the rocks compare closely, both structurally and mineralogically, with the variolitic late basic cone-sheets of Mull, and their chemical composition must be quite similar. As might be expected, they are comparable in many respects with the variolitic rocks associated with the Ben Hiant Intrusion (p. 171) and like them are compositionally related to the quartz-dolerites of Talaidh type which form the great Ben Hiant Intrusion and the bulk of the cone-sheets.

In another cone-sheet, referable to Centre 1, elongated felspars dominate the crystalline structure of the rock, while the augite and magnetite are more or less confined to the hyaline matrix (24468). In such rocks the texture is generally finer than in the true variolites, the augite may assume a branching and cervicorn development, and magnetite builds a fine-textured rectangular lattice, as well as occurring abundantly as small isometric grains. Such rocks are related to the pitchstones of leidleitic affinities, or are transitional between the true variolites and the variolitic and tholeiitic varieties of the quartz-dolerites of Talaidh type.

The Non-porphyritic Cone-sheets.—The majority of the non-porphyritic cone-sheets, mostly referable to Centre 2, but some related to Centre 1 (p. 178), are quartz-dolerites of a type that was particularly prevalent amongst the Late Basic Cone-sheets of Mull, and to which the name Talaidh Type was applied on account of their development in the region of Beinn Talaidh in that island.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 304–305.

They are generally fine-grained rocks, rich in iron-ore, which are dark brownish-grey in colour and are usually devoid of olivine. They are composed of a moderately basic plagioclase felspar, augite, titano-magnetite, alkali-felspar of a preponderating albitic character, and quartz. The outstanding feature of these rocks is not to be found so much in their mineral composition as in their structure. There has been an early separation of the larger and more basic constituents from an acid residuum that remained fluid till the last, and which was capable of migration and segregation into well-defined but unevenly distributed areas. The rocks, therefore, consist of an open mesh-work of indefinitely bounded elongated crystals of labradorite-andesine felspar, which embraces crystals of augite and has its interspaces filled with a copious fine-grained mesostasis of alkali-felspar and quartz (21439, 21441). Augite and attendant titano-magnetite are usually the earliest products of consolidation. The augite thus generally avoids an ophitic structure and has a hypidiomorphic-columnar habit, building somewhat stumpy crystals bounded by prism and pinacoid faces and elongated parallel to the *c* axis. It is a normal aluminous variety of a brownish colour, and seldom shows the lilac tinge attributable to a high content of titanium. Magnetite, or titano-magnetite, occurs chiefly in association with the augite, intergrown with the peripheral portions of the augite crystals, but iron-ore also builds isolated crystals and in some instances appears to be ilmenite.

The mesostasis is a fine-grained crystalline mass, usually turbid with secondary products, with an acicular to granular type of crystallization of its constituents. The main elements are alkali-felspar and quartz, but acicular augite is of frequent occurrence. The felspar is mainly albite, but potash-felspar is also present and this may be distinguished in fine graphic intergrowth with quartz. Quartz also is segregated into small isolated areas representing the ultimate excess of silica. Apatite, as has been found to be the case with most of the rocks that have an acid mesostasis, is concentrated in this partial magma, and in some instances becomes an abundant constituent.

The analysed specimens are both from thick representatives of the Outer Set connected with Centre 2, and are of Talaidh type. One sheet (23296) is a moderately fine-textured rock that shows an almost simultaneous crystallization of augite and felspar, so that the augite exhibits both a columnar and a subophitic habit. In this respect the rock shows a slight leaning towards the coarser varieties of quartz-dolerite in which an ophitic structure is more general. The other sheet (22819), probably on account of its thickness, is a still coarser variety of the Talaidh type in which the augite exhibits a subophitic habit. The mesostasis is abundant and has the characteristic variable distribution.

A review of the analyses given on p. 82, and a comparison with those of the Talaidh cone-sheets of Mull,[1] show that the type as a whole is very constant in its chemical composition and is one that must mark a quite definite stage in the process of differentiation. It is interesting to note, as pointed out in connexion with the Ben Hiant Intrusion, that the cone-sheets have practically the same chemical composition as the Ben Hiant mass. The size of the Ben Hiant mass and its intrusion as a unit prove that a magma of Talaidh composition was, on occasion, produced and intruded in bulk. At the same time, microscopic examination of these rocks shows that such a magma during the process of solidification would, and did, give rise to an acid partial magma that was capable of self-expression, provided mechanical separation of liquid from solid fractions could be effected. That such a separation actually took place in certain instances is more than conjecture, and the results of this process are discussed elsewhere (p. 95).

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 17.

Of the cone-sheets related without question to Centre 1, in addition to those referable to the Talaidh type (24470), there are others, usually non-porphyritic, which are either variants of, or depart more or less widely from, this type. Slight variants of the Talaidh type are furnished by sheets of moderately fine-grained quartz-dolerite. One of these (24469), cutting Moine Schists to the north of Loch Mudle, has small hypidiomorphic-columnar crystals of augite and laths of labradorite felspar in an apatite-rich residuum of alkali-felspar and quartz. Its main difference from the Talaidh type lies in the occurrence among its constituents of small flakes of biotite and brownish-green hornblende, both of which appear to be original and not due to subsequent thermal alteration.

A certain number of sheets occurring in a zone to the south-east of Ben Hiant, and seen as discontinuous outcrops, are subacid in composition and moderately coarse in texture. As represented by a typical specimen (21438), they are microporphyritic, containing small crystals of labradorite-andesine felspar which reach a sixteenth to an eighth of an inch in length. The bulk of the rock, however, is a mass of elongated blade-like crystals of decomposed augite and elongated, irregularly bounded, crystals of oligoclase-andesine with interstitial slightly turbid feathery aggregates of alkali-felspar and quartz. Quartz also is segregated into small clear patches. These rocks certainly show affinities to the quartz-dolerites and may be regarded, perhaps, as acid representives of the Talaidh type.

Of the widely variant types we may cite a sheet that occurs at the bridge over Allt Tòrr na Mòine, half a mile east-north-east of Bourblaige (24467). It is a grey compact splintery rock with small porphyritic felspars that reach a few millimetres in length. The microporphyritic constituents are a moderately basic plagioclase and relatively infrequent augite pseudomorphed by calcite. These occur in a matrix that has an acicular to feathery type of crystallization and is full of blade-like and skeleton crystals of augite. The residuum was presumably glassy and the feathery crystalline aggregate of quartz and alkali-felspar which constitutes the base is probably in part due to devitrification. The rock is closely allied to the pitchstones, and although its somewhat decomposed condition makes its precise classification a matter of difficulty its microstructure is reminiscent of the inninmorite-pitchstones of Mull.[1]

Passing now to non-porphyritic sheets referable to Centre 2, we find a number of departures from the usual Talaidh type of quartz-dolerite.

A thick sheet exposed on the shore at Rudha Groulin (21443), while having the structures and general composition of the normal quartz-dolerites, has the somewhat unusual occurrence of a colourless rhombic pyroxene (enstatite) as small ill-shaped crystals, in addition to hypidiomorphic-columnar augite. There has been a slight development of biotite as the result of contact alteration by the later plutonic rocks.

What may be regarded as a variable and basic representative of Talaidh type is represented by a sheet exposed on the shore of Rudha Àird an Iasgaich, south-west of Kilchoan (p. 175). The sheet is about 21 ft. in thickness. The outer 6 ft. on both sides consists of a coarse-textured, spheroidally-weathering rock, with well-chilled margins, while the central 9 ft. exhibits vertical jointing; in the centre of this latter portion is a lenticular xenolithic mass, some 20 yds. long, which contains abundant xenoliths of schist and other rocks closely packed in a quartz-dolerite matrix. The upper surface of the sheet is in contact with calcareous Liassic shales that have suffered considerable contact alteration.

While the margins of the sheet against the Liassic strata above and below are well chilled, there is no internal chilling, and the sheet is presumably a composite intrusion.

The coarse marginal zones (22231) may be described as of quartz-gabbro composed of a brownish subophitic augite, moderately well-formed interlocking crystals of zoned labradorite, magnetite, and an interstitial acid mesostasis of alkali-felspar and quartz. The mesostasis is collected into relatively large areas and exhibits a fine-textured to skeletal type of crystallization. Where it is in contact with felspar it has produced resorption and acidification, and against augite has effected the formation of brown hornblende at the expense of the pyroxene. That the rock has been subjected to stress and movement during consolidation is shown by the frequently bent and curved cleavage planes in the augite and felspar crystals, similarly observed in some of the quartz-dolerites of Mull[2] and elsewhere.

The vertically jointed interior of the sheet (22232), though generally fine-textured, is variable, and in the same section it is possible to pass from a moderately coarse quartz-dolerite with subophitic augite to a finer-grained rock of Talaidh type. The rock has an almost xenolithic appearance, as if it had been churned up during its consolidation. As in the outer zones, curved augite crystals are often encountered and there has been a local precipitation of augite that is hard to account for except on a xenolithic hypothesis. The rock contains a small amount of brown hornblende intergrown with the augite and forming small isolated patches in the mesostatic material.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 282–284.

[2] *Ibid.*, pp. 324–327.

The central xenolithic lenticular mass (22233) is presumably a later injection, for it is difficult to account for its highly xenolithic character and central position in any other way. It is a much more acid rock than the rest of the mass, and has undoubtedly still further acidified itself by the assimilation of acid gneiss, quartzite, and other xenolithic matter. The matrix in which the xenoliths lie is an acid type of quartz-dolerite characterized by small columnar to idiomorphic augites, irregular laths of labradorite, moderately large crystals of magnetite, and a copious acid mesostasis. In the neighbourhood of the siliceous xenoliths the rock is acidified, the mesostatic matter is more abundant, augite is more definitely idiomorphic, and at the actual contacts with the xenoliths there has been an excessive precipitation of augite in closely packed more or less idiomorphic crystals. The augite appears to be an ordinary aluminous variety with a moderately wide axial angle.

The xenoliths themselves have been much corroded and penetrated by magmatic matter. Quartz grains have suffered partial solution with the subsequent formation of tridymite fringes on the undissolved portion, and tridymite has also separated from the silicified melt. This mineral, as is usually the case, has reverted to quartz, and, where fringing incompletely dissolved grains, has the same crystallographic orientation as the original quartz.

It is not usual for individual cone-sheets to have produced any marked contact alteration of the rocks with which they come in contact, though the cumulative effect of many sheets is often apparent. In the case, however, of this particular sheet, partly owing to its thickness and partly because the Liassic deposits readily respond to thermal agencies, quite interesting metamorphic effects are to be observed at its contact. The calcareous Liassic shale (22234) has been indurated and has developed a suite of calc-silicates, amongst which are garnet, monoclinic pyroxene, idocrase, tremolite, and prehnite.

The garnet is colourless, well-shaped, and averages about ¼ mm. in diameter. The pyroxene is an aluminous variety. It occurs in elongated blade-like crystals of a greenish tint, and is usually edged with aegirine, due probably to the amount of alkali in the original rock. Tremolite is detectable chiefly by its habit, but a few small patches have escaped the general replacement by calcite, while prehnite builds small rectangular crystals with the usual moderately high birefringence. In addition there is a mineral developed somewhat irregularly, with low birefringence and apparently straight extinction, which is most probably scapolite, but its determination is doubtful. Sphene occurs in brownish granules and patches that reach 0·1 mm. in size.

A few moderately coarse-textured non-porphyritic sheets occurring on the southern side of the ring-dyke complex are referable to quartz-dolerite. They show affinities with the tholeiites and are characterized by subophitic yellowish slightly pleochroic augite, and elongated felspars that occasionally show a stellate grouping. Generally they are olivine-free (21844), but in some cases olivine may have been an original constituent (21847). A certain amount of mesostatic matter, usually chloritized, is present, and quartz appears to have been an original product of consolidation.

The Porphyritic Cone-sheets.—All the sheets here considered carry phenocrysts of plagioclase felspar. As has been stated already, they show a tendency to group themselves near to the plutonic centres. The majority belong to Centre 2, but some may with certainty be co-ordinated with Centre 3.

Relatively few of the porphyritic sheets occur beyond the limits of the ring-dyke complex, and most of them are more or less close to the boundary of the Hypersthene-gabbro Ring-dyke of Centre 2. They have, therefore, in most instances suffered the effects of thermal metamorphism, usually in the form of granulitization of the matrix and the development of biotite from iron-ores and chlorite. Their major structures, however, are retained, and we are enabled to state that these porphyritic rocks are classable as ordinary porphyritic basalts and dolerites. There appears to be no essential difference between the porphyritic sheets that are respectively referable to the various centres, and they find their equivalents in the porphyritic types of Early Basic Cone-sheets and small-felspar basalts of Mull.

A representative of the porphyritic cone-sheets referable to Centre 2 (22236), which occurs on the shore near Mingary pier, and is far enough away from the plutonics of Centre 2 to have escaped metamorphism, may be described as a porphyritic basalt or dolerite. It contains small crystals of a moderately basic labradorite in a matrix of felspar laths, grains of magnetite, and a brownish micro-ophitic augite that reproduces in a measure the well-known 'ophimottled' structure. A group of sheets from the neighbourhood of Maol Buidhe, also beyond the range of contact metamorphism, are of the same general character, their chief variation being in the texture of the matrix rather than in their mineral composition. The matrix may be either definitely ophitic (21837) or finely hypidiomorphic-granular (21836).

A well-chilled sheet (22369) that cuts the Glas Bheinn Porphyritic Dolerite exhibits the usual character of bearing small unzoned porphyritic labradorite felspars in its fine-textured chilled edges. The dolerite in contact shows signs of shattering and both rocks have suffered thermal alteration by later ring-dyke intrusions.

Sheets still beyond the boundary of the ring-dykes, but sufficiently close to be thermally altered, occur between Kilchoan and Beinn na Seilg. Some of these were hypidiomorphic granular basalts (22246, 22679) with olivine, others (21820) were porphyritic olivine-bearing basalts with a subophitic matrix. All have suffered granulitization, and otherwise show changes that will be discussed in detail when dealing with the metamorphic effects of the ring-dykes.

BASIC CONE-SHEETS CUTTING MEMBERS OF THE PLUTONIC COMPLEX OF CENTRES 2 AND 3

The majority of these sheets are porphyritic in character, some referable to normal basalts and dolerites, others to quartz-dolerites.

Amongst those that cut the Hypersthene-gabbro, a typical sheet near the summit of Beinn na Seilg (21564) has porphyritic zoned labradorite-andesine felspars that range up to 3 mm. in length, and occasional porphyritic crystals of augite, in a matrix of irregularly bounded laths of zoned plagioclase with interstitial magnetite and augite. Slight thermal alteration has modified the texture of the matrix to a small extent only.

The edges of such sheets (22277) are well chilled against the gabbro, which may show slight signs of shattering at the contact. The chilled edge usually carries unzoned porphyritic crystals of labradorite and sometimes of augite in a fine-textured magnetite-rich basaltic matrix.

Amongst the sheets that cut the old Quartz-gabbro of Garbh-dhail (c of Pl. V), both basalts and quartz-dolerites are represented; the majority are porphyritic, and almost all show the effects of contact metamorphism due to the later members of the ring-dyke complex. In the basaltic varieties the porphyritic crystals reach 3 or 4 mm. in length, and the matrix is either hypidiomorphic-granular (21572), or the augite is granular to subophitic (21819). The quartz-dolerites have porphyritic zoned labradorite felspars in a matrix of interlacing laths of labradorite-oligoclase, magnetite, and columnar to subophitic augite, with an acid residuum containing free quartz. Such sheets (22681, 24445), occurring to the north-east of Beinn na Seilg, are older than, and have been metamorphosed by, the Quartz-gabbro of Centre 3 (A of Pl. V) (p. 184). They have had their original augite granulitized, and biotite developed at the expense of chlorite; while the chloritized residuum with free quartz has given rise to aggregates of biotite and small well-formed crystals of rhombic pyroxene (hypersthene).

A porphyritic basaltic sheet (22311) that cuts the basalt lavas and agglomerates on the inner margin of the Old Gabbro of Lochan an Aodainn (b of Pl. V) carries porphyritic labradorite and augite, often in glomero-porphyritic groups, in a fine-textured microlithic to granular matrix rich in magnetite and apatite. In the nature of its porphyritic constituents it is similar to certain basaltic sheets that cut the Hypersthene-gabbro, and which are described above.

A representative of certain sheets that cut the basalt and agglomerate capping of Meall an Tarmachain (21854), and which are dispositionally related to Centre 3, is especially interesting on account of its metamorphism proving conclusively that this group of sheets, although related to Centre 3, is earlier than the Great Eucrite of that centre. It is a porphyritic quartz-dolerite with porphyritic crystals of zoned labradorite, which reach a quarter of an inch in length, in a matrix of felspar laths, magnetite, moderately large subophitic augites, and an interstitial quartz-bearing acid mesostasis. The metamorphism has produced the usual turbid schillerization of the felspars, partial granulitization and schillerization of the augite, and the development of granular rhombic pyroxene and biotite in the siliceous mesostasis.

SILLS AND OTHER SHEET-LIKE MASSES

A number of sheet-like masses, occurring mostly in the bedded strata beyond the limits of the ring-dyke complex, will here be considered. Some of these are possibly true sills, but others are most probably aberrant representatives, or extensions, of cone-sheets. The basic examples call for no special comment, for with one exception they are of types well represented amongst the cone-sheets. They are chiefly non-porphyritic rocks referable to varieties of the Talaidh type of quartz-dolerite (21434), which sometimes present a pronounced variolitic structure (21435). The most important and perhaps the most interesting example is the thick subacid sheet well exposed on the shore beneath Mingary Castle (p. 185). It is a compact greenish-grey, finely-speckled rock with decided granophyric affinities (22430). Like most of the subacid sheets, as also the acid portions of the composite intrusions, it is rich in soda-felspar. It consists of elongated crystals of augite, pseudomorphed in chlorite or partly replaced by brownish hornblende, and elongate crystals of oligoclase, in a matrix of alkali-felspar and quartz. The matrix has a feathery to acicular type of crystallization, with, here and there, definite micrographic intergrowths of potash-felspar and quartz. Generally, the felspar of the matrix appears to be albitic. Magnetite as grains is commonly associated with the augite, and pyrites occurs in small isolated patches. The rock is similar to the acid craignurites of Mull[1] and may be classified as a granophyre of craignurite affinity. Another subacid sheet, exposed on the shore 750 yds. west by south of Mingary Castle (21437), is of similar type, except that the acicular type of crystallization characteristic of the craignurites is less pronounced. The rock has a more bostonitic structure with a tendency for the felspars to assume a less elongate form. There is a good deal of micrographic matter in the base, and the rock may be described as a somewhat basic soda-granophyre.

A large intrusion (21843) striking with the cone-sheets, but cut by them and having vertical junctions with the Lower Lias shales, occurs on the western side of Kilchoan Bay, 300 yds. south-west of the jetty. It is a fine-textured grey speckled rock that, under the microscope, presents a very mixed appearance. It consists of relatively basic clots of augite, albitized labradorite felspar, and magnetite in a feathery felspathic matrix of albite-oligoclase, orthoclase and quartz with subordinate acicular augite. The basic portions are rich in augite that shows serpentinous decomposition and the approximately uniaxial character typical of the enstatite-augites. The pyroxene usually has a subidiomorphic habit, but it may also take on a subophitic relationship to the plagioclase, when it frequently shows the effects of pressure and movement by the curving of its cleavage-planes.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, pp. 226, 227.

This association of enstatite-augite with labradorite in glomero-porphyritic groups was, in Mull, not an unfamiliar feature of certain of the more acid craignurites, and the rock under description would find its place in this group.

A unique occurrence of an extremely basic sheet of plateau basalt type occurs within the lavas of the Ardslignish outlier, and is lettered eD on the Memoir-map. It forms a thick columnar sheet, trending in a north-westerly direction, and is cut by a north-west dyke. Judged by the inclination of the columns, the sheet dips at 30° to the south-west. A specimen collected one and a half miles north of Ardslignish farm (24477) is a dark-grey finely crystalline olivine-dolerite. It is composed of abundant olivine, almost wholly fresh, a deeply tinted titaniferous augite, strongly zoned basic labradorite felspar, titano-magnetite, and interstitial turbid analcite. The olivine, a colourless variety, has a marked tendency towards idiomorphism. It occurs in somewhat rounded grains, isolated crystals and glomero-porphyritic groups, and has preceded the crystallization of all other constituents. The felspar forms a coarse mesh-work of moderately large elongate crystals and is ophitically embraced by the titaniferous augite. The iron-ore is associated more particularly with the augite and has given rise to a little biotite in its immediate vicinity. Analcite is not an abundant constituent, but occupies well-defined areas that represented ultimate intercrystal spaces.

A number of north-westerly directed sheets cut the eastern extremity of the Glas Bheinn Porphyritic Dolerite (p. 143), and are also encountered cutting the Lower Lias limestones to the east of Beinn na h'Urchrach, on the north side of Ben Hiant. They all appear to be quartz-dolerites of which some exhibit a subvariolitic structure reminiscent of the subvariolitic rocks of the Ben Hiant Intrusion (p. 172). These variolitic varieties (22431, 22703) are rich in titaniferous augite and titano-magnetite, the former in elongate blade-like crystals and cervicorn groups, the latter as plates and grains intimately associated with the augite. The matrix presents an acicular and skeletal type of crystallization indicative of relatively rapid solidification.

Other sheets of this group, less basic in composition and paler in colour, may be described as subvariolitic varieties of the Talaidh type (21436). They have semi-columnar crystals and stellate groups of augite and felspar in a feathery matrix; but, with a more pronounced columnar and cervicorn habit of the augite, they become normal representatives of the type (22705).

METAMORPHISM BY CONE-SHEETS AND SILLS

As has already been stated, the metamorphism effected by individual cone-sheets is not particularly well marked, and even in the case of the thicker sheets is confined to the actual contact. The cumulative metamorphic effect of numerous contiguous sheets is, however, of a more pronounced character and may be impressed on the country rock over a relatively wide area. It is in the various sedimentary series, as might be expected, that the metamorphic changes brought about by cone-sheets are most in evidence, and the Liassic sediments seem particularly responsive. The igneous masses where cut by cone-sheets suffer little change even at the contacts, and it is chiefly in xenoliths of the country rock, where assimilative processes as well as contact metamorphism are active, that any radical changes are effected.

The conversion of Liassic limy shale into calc-silicate rock has already been dealt with (p. 190), but another type of interesting contact rock also results from the metamorphism of certain Upper Lias shales. Along the shore on the western side of Kilchoan Bay, the black shales in contact with the cone-sheets are frequently indurated, have lost their fissility, and become more granular. A microscopic examination shows that they have been converted into a turbid mass of highly birefringent prehnite, enclosing small prisms of idocrase and occasional small colourless garnets, and rendered turbid by dusty carbonaceous matter (21845). In certain parts the amount of unaltered finely-divided clastic quartz is considerable and clearly demonstrates the original clastic character of the rock.

COMPOSITE AND ACID INTRUSIONS

The majority of the acid and intermediate cone-sheets, and those more acid sills associated with the cone-sheet complex, have a marked tendency to exhibit a composite character, and as in Mull do not appear to be confined to any particular period of intrusion although most are included in the Outer Set of Centre 2. They almost invariably have basic edges which show a merging junction with an acid interior. In some cases there is perfect petrological gradation from one rock to the other, but in other instances the later acid intrusion has hybridized with the already intruded basic rock to a varying degree, and produced xenolithic and other abnormal features.

The rock types represented are mainly varieties of the Talaidh type of quartz-dolerite associated with granophyres that are more than usually rich in soda-felspar. There does not appear to be that prevalence of tholeiitic margins as was a feature of the composite sheets of Mull.[1]

One of the best examples of a composite sheet may be studied on the shore, to the south of Mingary Pier (22227–30, 21855–6). The basic edge (22228), which has a thickness of 1½ ft., is best described as a subvariolitic quartz-dolerite of Talaidh type. Its augite, which is titaniferous, occurs in elongated and occasionally curved crystals that are crossed by plates of magnetite after the manner of the variolites ; also, there is a good development of augite presenting that cervicorn structure which was found to be characteristic of the augite in many of the Late Basic Cone-sheets of Mull.[1] The felspars are elongated and about andesine in composition, while the matrix is largely chloritic. The intermediate portions (22229), and the more basic portion of the acid interior (21855), are of albite-granophyre that has been basified by the resorption of earlier basic material. The rock consists of a few large resorbed crystals of a relatively basic plagioclase set in a fine-textured matrix of oligoclase, alkali-felspar, and abundant free quartz. The central portion (21856) is a granophyre rich in soda-felspar. It contains large turbid crystals of albite in a definitely micrographic matrix of alkali-felspar and quartz, which includes a moderately large proportion of albite. The lower intermediate part of the intrusion (22230), and the outer portion of the acid interior, carry more basic xenoliths, which may in a measure be regarded as cognate. These xenoliths are of a non-variolitic fine-textured quartz-dolerite of Talaidh type, and are similar in composition to portions of the basic margins.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 228.

Another composite sheet, that has well-defined basic margins about 1½ ft. in thickness and an acid interior measuring some 6 ft. across, occurs about one third of a mile north-east of Sròn Bheag, and a quarter of a mile north-east of the Sròn Bheag intrusion described below (p. 197). The margins (21823), as in the composite sheet mentioned above, are of a variolitic quartz-dolerite that consists of elongated frequently-curved crystals of titaniferous augite, similarly elongated crystals of oligoclase-andesine felspar and irregularly distributed patches of magnetite in a fine-textured matrix of augite, plagioclase, and residual quartz. The pyroxene of the matrix shows to perfection the cervicorn structure so frequently adopted by augite in rocks of this character and composition.

The more acid central portion (21822) is also a quartz-dolerite of Talaidh type, but a much more acid variety. The more siliceous character is indicated by a much paler tint in the hand-specimen, and microscopically by a superabundance of alkali-felspar and quartz in its composition. The rock contains moderately large turbid crystals of albite-oligoclase felspar, and crystals and clots of hypidiomorphic augite, in a subvariolitic matrix of narrow elongated crystals of decomposed pyroxene and sheaf-like aggregates of oligoclase, with a residual base of alkali-felspar and quartz.

The ultimate products of consolidation would appear to have a composition similar to that of the soda-granophyres and felsites that frequently form the central portions of the thicker composite intrusions. The central portion of this sheet is locally xenolithic and basified by partial or complete resorption of the earlier basic material.

In some instances the acid central components are of a felsite that approaches pitchstone in character and are rocks that suggest an originally glassy texture. One such mass (21442), apart from a few crystals of plagioclase that may well be xenolithic, consists of mutually interfering areas of alkali-felspar and quartz, replete with trichites. It has a structure that is due presumably to devitrification, and shows a tendency towards the development of spherulitic, radial, and sectorial growths of quartz and felspar.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 302.

An acid cone-sheet (21811), unaccompanied by basic margins, is intruded into the Hypersthene-gabbro to the north of Plocaig. It is a fine-textured rock containing isolated crystals of augite which appear to be xenolithic, and which are rendered almost opaque by the separation of magnetite. The only other constituent of any size is a plagioclase felspar that occurs as crystals of one or two millimetres in length, and consists of acid labradorite zoned to oligoclase. The matrix is a feathery mass of alkali-felspar and quartz in which both soda-felspar and orthoclase are represented, and which contains abundant small pseudomorphs after acicular augite. The ultimate products of consolidation are orthoclase and quartz in extremely fine micrographic intergrowth. The rock is a somewhat basic granophyre that has further basified itself by the resorption of basic matter of Talaidh type. In the structure of its matrix it somewhat resembles the more acid varieties of the craignurites of Mull,[1] but this structure is probably in part dependent on its basification rather than upon its original composition. At the contact, the Hypersthene-gabbro (22267–8) shows signs of crushing and is traversed by veins from the acid sheet which have assimilated gabbro material. The effect has been a general basification of the sheet and the precipitation of a greenish augite at and near its junction with the gabbro and xenoliths. The gabbro itself seems to have suffered no appreciable contact alteration.

Sròn Bheag Composite Intrusion.—In this composite dyke-like mass striking hybridization has taken place between the component members. A basic interior, consisting of quartz-dolerite, forms the most prominent feature of the headland of Sròn Bheag, at the south-western extremity of Kilchoan Bay, and is lettered eD on the geological maps. It is some 200 to 300 ft. broad, and is seen to extend steeply or vertically up the face of the sea-cliff. It can be traced inland for a distance of about a quarter of a mile. The quartz-dolerite is accompanied on either side by similarly orientated intrusions of felsite or granophyre of bostonitic affinity, 50 to 100 ft. in width. These acid masses are well seen on the shore and in the sea-cliff, but have not been traced far inland. The upper part of the more easterly mass, however, appears to extend as a sill among the Inferior Oolite sediments that form the country rock.

The junctions between the felsitic masses and the quartz-dolerite are in some places relatively sharp, but more frequently the rocks merge into each other. Such indefinite contacts are well seen on the south-westerly side of the quartz-dolerite, and here, also, acid veins that profusely cut the quartz-dolerite are best developed. The basic rock is traversed by bands of breccia which have been invaded by felsitic matter and which may well be due to the explosive action of the acid magma. These merging junctions between the basic and acid masses of Sròn Bheag suggest that this complex is akin to the composite intrusions, but differs from the great majority in that the later acid magma has intruded itself along the margins, and not in the centre, of the earlier basic intrusion.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 227.

The basic and acid intrusions of the Sròn Bheag composite mass are alike traversed by quartz-dolerite cone-sheets that belong to the Outer Set of Centre 2, and thus the complex as a whole is of early date. The possibility that it may belong to the cone-sheet complex of Centre 1 has already been considered (p. 179), but it is also possible that its north-westerly orientation may have been induced by regional, rather than local, tensional stresses.

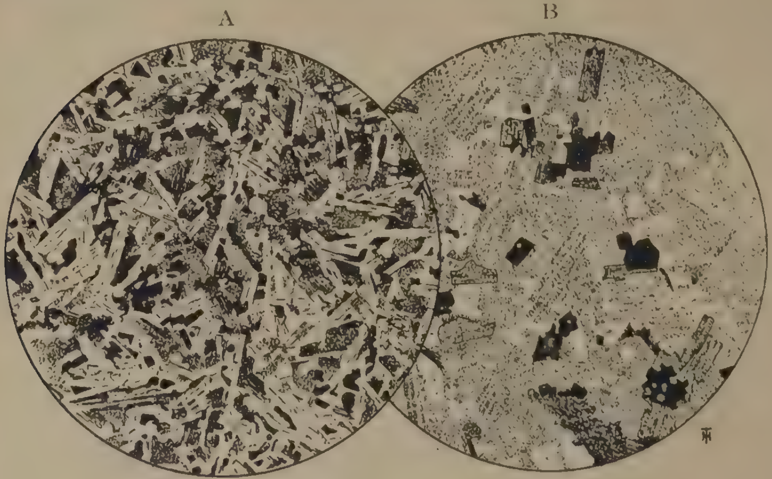

FIG. 26.—*Composite Intrusion of Sròn Bheag.*

A. (21825A) × 20. *Basic central portion of intrusion originally a quartz-dolerite of Talaidh type. Now modified by the intrusion of acid material and the consequent development of biotite. The rock retains its doleritic texture (see below).*

B. (21827) × 20. *Acid portion of the same mass consisting mainly of alkali-felspar, both soda and potash varieties, quartz, and fairly large crystals of fox-red biotite.*

The basic, and here central, portion of the intrusion (21825 A, 21828) was originally, before modification by the incoming acid magma, a moderately basic quartz-dolerite of Talaidh type. It appears to have consisted of elongated columnar augites, charged with magnetite or otherwise associated with iron-ore, and elongated crystals of albitized labradorite, in the usual matrix of plagioclase felspar and quartz, with subordinate orthoclase. As now encountered it is modified to a great extent by acid material that has penetrated it in all directions from the subsequently intruded granophyre or bostonite. The augite is pseudomorphed in chlorite, and abundant fox-red biotite has developed throughout the rock between the felspars, and in association with the augite and iron-ores. The plagioclase felspars are frequently reduced to the condition of albite-oligoclase, and fibrous bastite pseudomorphs suggest that a rhombic pyroxene was one of the products of hybridization. Acid veins penetrate the more basic material and cut the rock up into isolated and relatively basic areas.

The acid portion of the intrusion was presumably bostonitic in character for phenocrysts of perthite (21827) are of common occurrence. Their average size is about three or four millimetres, but they may reach a centimetre in extreme cases. The rock as a whole is light-grey in colour, but has a very mixed aspect. The perthitic phenocrysts occur in a mosaic of mutually interfering squarish crystals of oligoclase, albite-perthite, and anorthoclase; more or less isolated, and occasionally pseudomorphed grains of augite; and abundant patches of red biotite with interstitial quartz and occasional small areas of micropegmatite.

The rock may be regarded as a thoroughly basified and contaminated soda-granophyre or bostonite. The contained augite is either largely a product of imperfect assimilation or clearly xenolithic (21829), while the biotite has resulted from the complete interaction of acid and basic material, involving in the latter an enrichment in silica and alkalis.

As the more basic portion of the mass is approached, the acid margins (21826) take on a darker tint and are studded with small bright phenocrysts of albitized labradorite, with albitic peripheries, and albite. There has been a local development of hypidiomorphic pale-greenish augite as large thick-set crystals, and fairly abundant biotite. The basic material is included as clots, against which there is a strong development of augite and biotite. The fine basic portions have the microstructure of a quartz-dolerite of Talaidh type, but they have been completely changed by metamorphism and hybridization. These portions show a vesicular structure, and it is worthy of mention that Dr. Harker[1] and others have noted the development of vesicles in rocks of a modified nature, and have attributed such to the liberation of gas or steam resulting from the interaction of an acid magma upon a basic rock recently consolidated.

In the more basic areas, the felspar occurs as narrow irregularly bounded laths of acid labradorite with albitic fringes. Augite is granular and abundant, as also is scattered magnetite, while actinolitic and chloritic patches and grains probably represent a rhombic pyroxene. There is also a general distribution of fox-red biotite, in moderately large plates, which becomes more particularly abundant in the more siliceous and alkaline areas.

The vesicular cavities mentioned above are usually lined with augite, but either augite and plagioclase, or biotite, may occupy the central regions.

We see clearly that the more or less normal quartz-dolerite of the central mass (21825 A) has been completely granulitized and contaminated by the acid magma, which in its turn has been modified by the assimilation of basic material. This mass as a whole constitutes, perhaps, the most instructive example of hybridization met with in Ardnamurchan and is directly comparable to instances cited by Dr. Harker from the Island of Skye. H.H.T.

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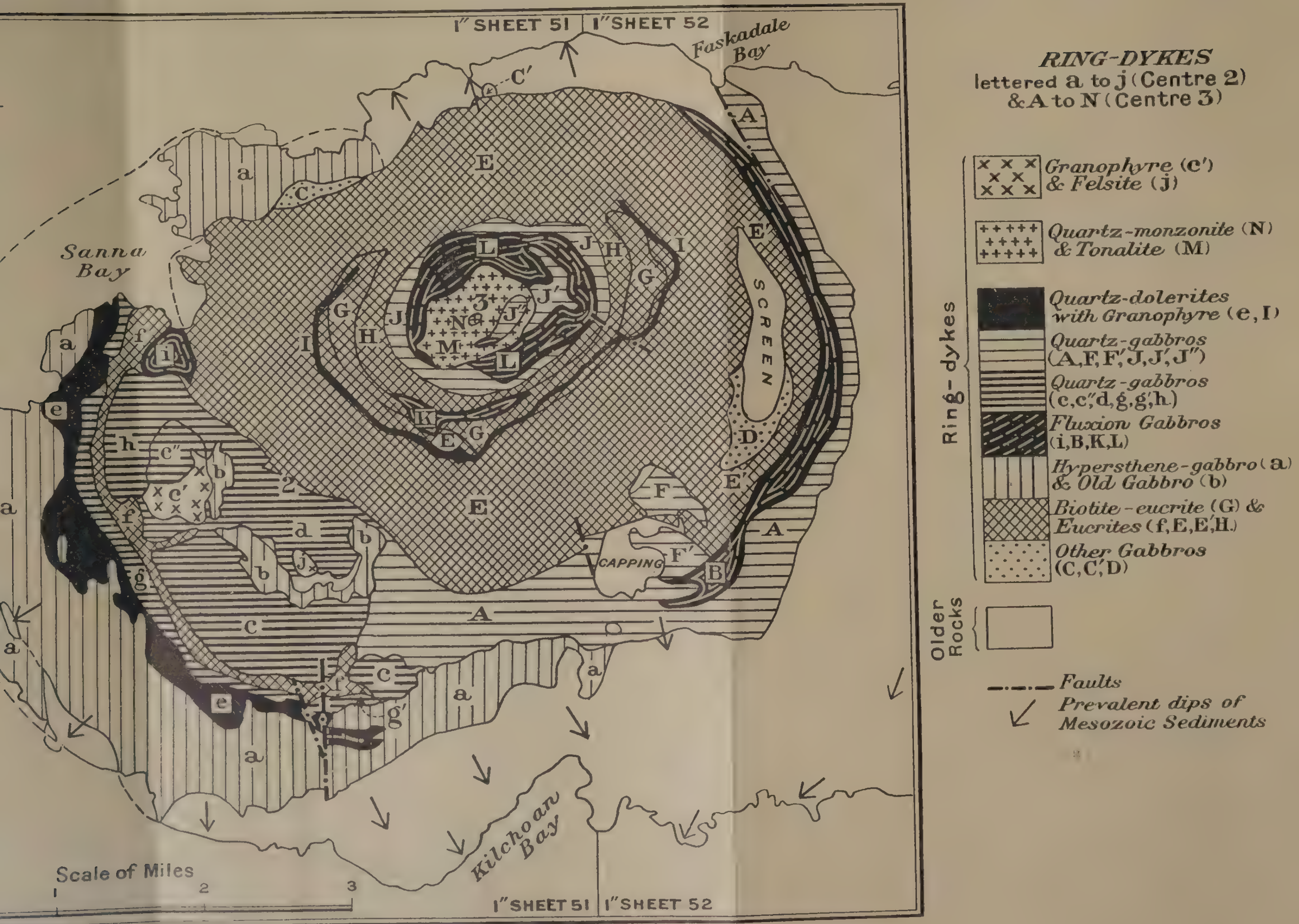
[1] 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, pp. 175, 185.

nan. INDEX MAP OF RING-DYKES OF CENTRES 2 AND 3, ARDNAMURCHAN. PLATE V.



1" SHEET 51
1" SHEET 52
Faskadale Bay
Sanna Bay
Kilchoan Bay
SCREEN
CAPPING
A
B
C
C'
D
E
E'
F
F'
G
H
I
J
J'
J"
K
L
M
N
2
3
a
b
c
c'
c"
d
e
f
g
g'
h
i
j
Scale of Miles
1
2
3
RING-DYKES
lettered a to j (Centre 2) & A to N (Centre 3)
Ring-dykes
Granophyre (c') & Felsite (j)
Quartz-monzonite (N) & Tonalite (M)
Quartz-dolerites with Granophyre (e, I)
Quartz-gabbros (A, F, F', J, J', J")
Quartz-gabbros (c, c", d, g, g', h.)
Fluxion Gabbros (i, B, K, L)
Hypersthene-gabbro (a) & Old Gabbro (b)
Biotite-eucrite (G) & Eucrites (f, E, E', H.)
Other Gabbros (C, C', D)
Older Rocks
Faults
Prevalent dips of Mesozoic Sediments

CHAPTER XV

TERTIARY RING-DYKES OF ARDNAMURCHAN
INTRODUCTION

The Ardnamurchan ring-dykes occupy a roughly oval area, 6 miles long by 4 miles across, the longer axis of which extends north-east. They form two distinct complexes, grouped about Centres 2 and 3 (*see* Pl. II). The earlier complex lies to the south-west and is in part replaced by the later complex lying to the north-east. To the west and north, the earlier complex is also encroached upon to some extent by the sea.

The present chapter has been written in order to provide a more comprehensive introductory account of the ring-dykes than that given in Chapter VII.

TABLE VII

RING-DYKES OF CENTRES 2 AND 3

Index Letter on Map, Pl. V.	Symbol on Memoir-Map.	Rock-type and Designation.	Relative Ages, as determined by contact relationships (pp. 206–8)	
			Younger than	Older than
		EARLIER COMPLEX, CENTRE 2.		
		Older than Inner Cone-sheets.		
a	rE	Hypersthene-gabbro of Ardnamurchan Point	—	c, e, A, C, E.
b	oE	Old Gabbro of Lochan an Aodainn	—	c, c′, d, A.
c	qE	Quartz-gabbro of Garbh-dhail	b.	c′, f, A.
c′	G	Granophyre of Grigadale	c, b.	? c″.
c″	qE	Older Quartz-gabbro of Beinn Bhuidhe	? c′.	h.
d	qE	Quartz-gabbro of Aodann	b.	j, E.
e	gD	Quartz-dolerite of Sgùrr nam Meann	a.	g.
		Younger than Inner Cone-sheets.		
f	uE	Eucrite of Beinn nan Ord	c.	g, h, A.
g	qE	Quartz-gabbro of Loch Caorach	e, f.	—
g′	qE	Quartz-gabbro of Beinn na Seilg	e, ? f.	—
h	qE	Younger Quartz-gabbro of Beinn Bhuidhe	c″, f.	—
i	fE	Fluxion Gabbro of Portuairk	—	? E
j	G	Felsite, south of Aodann	d.	—

TABLE VII—*continued*

RING-DYKES OF CENTRES 2 AND 3

Index Letter on Map, Pl. V.	Symbol on Memoir-Map.	Rock-type and Designation.	Relative Ages, as determined by contact relationships (pp. 206–8)	
			Younger than	Older than
		LATER COMPLEX, CENTRE 3.		
A	qE	Quartz-gabbro of Faskadale	a, b, c, f.	E.
B	fE	Fluxion Gabbro of Faskadale	—	? E′
C	eD	Gabbro of Plocaig	a.	E.
C′	eD	Gabbro, south-east of Rudha Groulin	—	E.
D	eD	Porphyritic Gabbro of Meall nan Con screen	—	E, E′.
E	uE	Great Eucrite	a, d, h, A, C, C′, D.	F, I, K.
E′	uE	Outer Eucrite	? B, D.	? E, F.
F	qE	Quartz-gabbro of Meall an Tarmachain summit	E, E.′	—
F′	qE	Quartz-gabbro, south side of Meall an Tarmachain	—	—
G	bE	Biotite-eucrite	—	I.
H	uE	Inner Eucrite	—	—
I	gD	Quartz-dolerite, veined with granophyre	E, G.	—
J, J′, J″	qE	Quartz-biotite-gabbro	—	? L, M.
K	fE	Fluxion Biotite-gabbro of Sìthean Mòr	E.	—
L	fE	Fluxion Biotite-gabbro of Glendrian	? J and J′.	M.
M	tH	Tonalite	J′, J″, L.	N.
N	qH	Quartz-monzonite	M.	—

RING PATTERN

Each ring-dyke complex is built up of a number of annular or arcuate intrusions, of which the great majority are composed of some variety of gabbro. Until the area was mapped out in detail, the whole massif was believed to consist of a single large intrusion of gabbro, with a small central intrusion of more acid type. Different varieties of gabbro constituting distinct masses in intrusive relationship have now been recognized. Sometimes the fact that one type is intrusive into another can be easily determined; at other times its demonstration is a difficult matter, though indications of age-differences can be obtained. Again, sharp contacts between distinct rock-masses may be located, but no evidence whatever may be forthcoming as to which mass is the younger. It is noteworthy that such differences in the character of contacts are sometimes met with along the same intrusive margin.

The Earlier Ring-dyke Complex has its centre approximately below Aodann (Centre 2 of Pl. II), a point around which the majority of the cone-sheets are also arranged. The Later Complex is to be referred to a centre near Achnaha (Centre 3), situated 1½ miles to east-north-east of Centre 2. It will be seen on the Index Map (Pl. V) that ring-dykes of Centre 3 are elongated in an east-north-east direction. In Central Mull, a shift of the intrusion-centre has been also demonstrated, in this case in a north-west direction. The intrusions of the later centre there also show bilateral symmetry about the direction of the shift.[1]

The chief varieties of gabbro that constitute individual ring-dykes are:—eucrite, quartz-gabbro, hypersthene-gabbro, and fluxion gabbro. Of these, eucrite and quartz-gabbro are almost equal in amount, as measured by area of outcrop, and are much in excess of the other two varieties. Fluxion gabbro occurs not only as distinct intrusions, but also as marginal borders to ring-dykes composed of the other three types. More acid rocks form the central portion of the Later Complex composed of tonalite and quartz-monzonite, and also two small masses of granophyre included with the Earlier Complex. Unlike the other Tertiary plutonic complexes of Britain, granophyre plays but a small part in Ardnamurchan in forming individual intrusions. The granophyric mesostasis of the quartz-gabbros and quartz-dolerites should, however, be taken into account in considering the relative amounts of granophyric and gabbroic materials.

A striking difference between the ring-dyke complexes of Mull and Ardnamurchan is that the narrow screens of older rocks found so frequently in Mull between adjacent intrusions are seldom encountered in Ardnamurchan. The paucity of screens combined with the small range in composition has rendered the mapping in Ardnamurchan extremely difficult. On the other hand, absence of screens affords opportunity for determining the relative ages of contiguous intrusions. Such pre-ring-dyke masses as do occur help considerably in the elucidation of the geology. They not only form screens separating adjoining ring-dykes, but also a roof to the Quartz-gabbro (A).[2] They are greatly contact altered, and one mass, on Meall nan Con, forms the highest ground in the whole massif.

Advantages from the mapping point of view in Ardnamurchan, as compared with Mull, are that exposures are especially good, for the gabbros usually form rocky country, almost devoid of scree and sparse of vegetation; and that the ring-dykes are not cut by many minor intrusions, being for the most part free from cone-sheets.

Denudation has acted to a different degree on the various types of intrusive rock, so that some masses now stand up as ridges, while others have been weathered down to form hollows. A spectacular example of this differential weathering is afforded by a ring-dyke of eucrite (E), the most important of the ring-dykes of Centre 3. This mass, named the Great Eucrite, forms a complete ring, a mile or more in annular width and with a maximum diameter of 4 miles. It forms a conspicuous circular belt of high ground, and is bounded on its inner side by a ring of crags that enclose a central area of relatively low relief (Pl. VI, p. 321). The central area is carved out in its turn into curving ridges and hollows that mark the course of various ring-intrusions.

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[1] 'Tertiary Mull Memoir,' 1924, Pl. vi., p. 307.

[2] Index letters applied to ring-dykes in the text are explained on Table vii. and Pl. v., pp. 201–202.

The intrusive masses outside the Great Eucrite consist in large part of quartz-gabbro, as a rule weathering easily and forming relatively low ground. But other more resistant types are also found in the Earlier Complex south-west of the Great Eucrite, and there differential weathering has also modelled the country. Outcrops of eucrite (f), hypersthene-gabbro (a), an old gabbro (b), and also older quartz-gabbros (c) and (c″), where indurated by later intrusions in contact, all stand up to a greater or less extent above adjacent ground occupied by quartz-gabbro, quartz-dolerite, and granophyre.

Dyke Form

While the mapping of the various intrusions leaves no doubt as to their ring pattern, their dyke form is in most cases a matter of inference. Ring-dyke complexes, however, would appear to be a variety of stock-complex, and typical stocks,[1] as well as certain ring-dykes, are known to have steep outwardly inclined walls.

The majority of the ring-dykes in Ardnamurchan are too wide to enable any such generalization as to their inclination to be based on the contacts available. In some cases, indeed, contacts are quite irregular. Where intrusive margins extend up steep hillsides, abruptly crossing the contours, it is evident at any rate that the contact-surfaces of the intrusions concerned must be steep (*see* Fig. 36, p. 264). There is, however, no hill-face sufficiently extensive to enable us to say whether such junctions are in general vertical, or are inclined outwards from or inwards towards the intrusion-centre. Narrow ring-dykes on the other hand are better suited for affording evidence of inclination. In the only example in Ardnamurchan, the Quartz-dolerite (I), contacts with its walls are well exposed at two adjoining points in its course, at which the margins are inclined outwards at an angle of 70 degrees. But, in the absence of observed contacts elsewhere along the outcrop of the ring-dyke, it is not possible to affirm that this is its invariable inclination. In other Tertiary intrusive districts, an outward inclination of narrow ring-dykes has been also noted. In Mull, the Loch Bà Felsite Ring-dyke is seen to be so inclined along part of its course.[2] In Slieve Gullion, Ireland, another example has been recorded.[3] The margins of ring-dykes have therefore been drawn on the section (Fig. 27) with outward inclinations, although we consider that further information is required before this generalization can be regarded as established.

Internal structures resulting from the movement of magma and from its consolidation may afford evidence of the form of ring-

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[1] R. A. Daly, 'Igneous Rocks and their Origin,' New York and London, 1914, p. 103.

[2] W. B. Wright *in* 'Tertiary Mull Memoir,' 1924, p. 340.

[3] J. E. Richey, 'Tertiary Ring-dykes of Slieve Gullion, Ireland,' *Rep. Brit. Assoc.*, for 1928, 1929, p. 545.

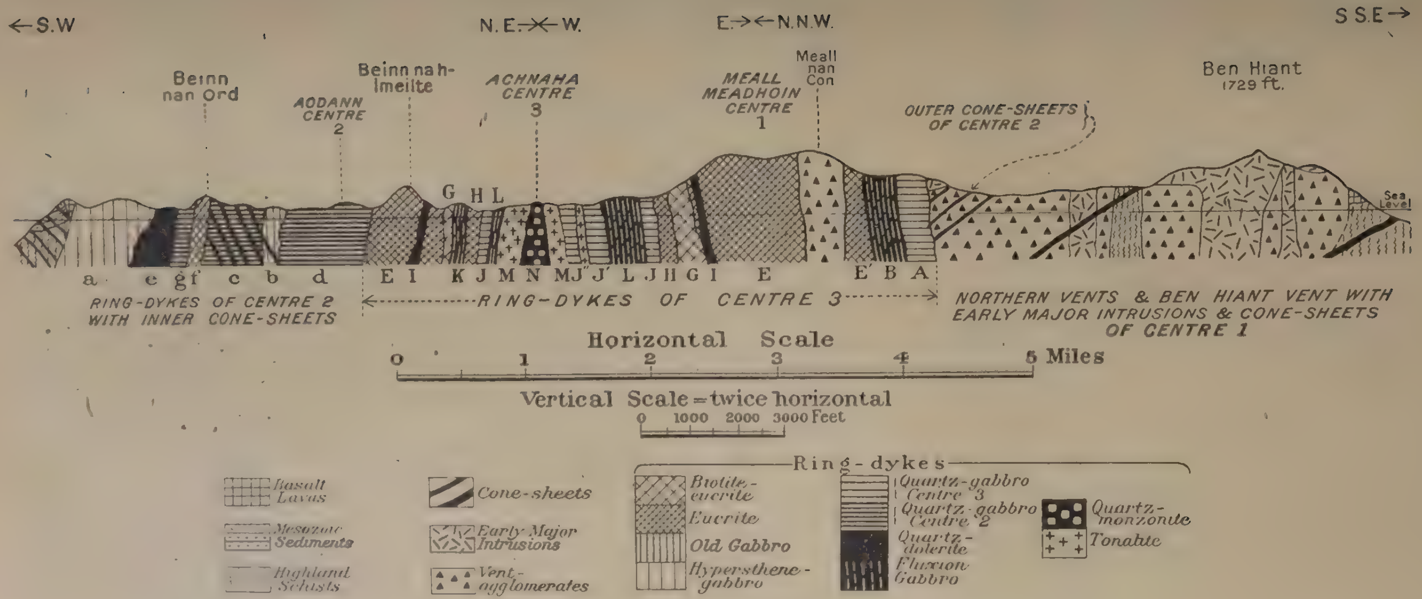
←S.W
N.E.→←W.
E.→←N.N.W.
S.S.E.→
Beinn nan Ord
AODANN CENTRE 2
Beinn na h-Imeilte
ACHNAHA CENTRE 3
MEALL MEADHOIN CENTRE 1
Meall nan Con
OUTER CONE-SHEETS OF CENTRE 2
Ben Hiant 1729 ft.
Sea Level
G H L
a e g f c b d E I K J M N M J″ J′ L J H G I E E′ B A
RING-DYKES OF CENTRE 2 WITH INNER CONE-SHEETS
RING-DYKES OF CENTRE 3
NORTHERN VENTS & BEN HIANT VENT WITH EARLY MAJOR INTRUSIONS & CONE-SHEETS OF CENTRE 1
Horizontal Scale
0 1 2 3 4 5 Miles
Vertical Scale = twice horizontal
0 1000 2000 3000 Feet
Basalt Lavas
Mesozoic Sediments
Highland Schists
Cone-sheets
Early Major Intrusions
Vent-agglomerates
Ring-dykes
Biotite-eucrite
Eucrite
Old Gabbro
Hypersthene-gabbro
Quartz-gabbro Centre 3
Quartz-gabbro Centre 2
Quartz-dolerite
Fluxion Gabbro
Quartz-monzonite
Tonalite

FIG. 27.—*Section across Tertiary Intrusive Complex of Ardnamurchan.*

Index-letters for ring-dykes are explained in Table VII, pp. 201–202.

dykes. Fluxion structures, such as flow-banding and the fluxional arrangement of crystals, are developed locally in the Hypersthene-gabbro (a), in the fluxion gabbros generally, and sometimes in quartz-gabbros and eucrites. Such structures strike, as a rule, parallel to adjoining margins of the intrusions concerned, and are usually either steeply inclined or vertical. The direction of the steeply inclined fluxion-planes sometimes varies without apparent reason either towards or away from the adjoining margin of the intrusion. In such cases, at any rate, it may be inferred that the intrusion is dyke-like in form. Sometimes inclinations as low as 45 degrees or less have been noted, but these are relatively infrequent.

In the Eucrites (E) and (H), pegmatite veins are often abundant, the wider and more persistent of which everywhere run parallel to adjoining margins of the parent intrusion, and are vertical or else highly inclined. Since the veins are evidently the infillings of contraction-cracks developed in the cooling mass, the regularly running individuals may be regarded as an indication of the steep nature of the ring-dykes concerned.

RELATIVE AGES OF THE RING-DYKES

The relative ages of the ring-dykes, so far as these can be determined, are indicated by the order in which the ring-dykes are lettered on Table VII and Pl. V. The kind of evidence on which the determinations of age are based is detailed below, while in succeeding chapters full descriptions of individual cases will be given under the heading of the various intrusions concerned.

Where in one intrusion, flow-banding, or a traversing dyke or sheet, is actually seen to be cut off by the margin of another intrusion, the interpretation is obvious. More often, however, relative ages have been deduced from the fact that one intrusion is baked by another at contacts; or that the later intrusion presents a marginal facies or a chilled margin against the earlier; or that the later intrusion bears xenoliths of the earlier. A satisfactory demonstration by such means can only be gained by very careful and close scrutiny in the case of gabbros, and in arriving at our conclusions the microscope has been a valuable aid. On the other hand, where more acid rocks, such as granophyre or tonalite, are in contact with gabbro, or with other acid masses, age relations are usually easily made out. The age of one intrusion relatively to another may also be disclosed by its preceding history. A mass shattered by explosion or sheared by crustal movements may be considered older than an adjoining mass that is quite sound.

The Earlier Complex of Centre 2 is regarded as entirely earlier than the Later Complex of Centre 3, for the outer intrusive margins of the outermost ring-dykes belonging to Centre 3 (A and E) transgress a large number of the cone-sheets and ring-dykes belonging to Centre 2. The Hypersthene-gabbro Ring-dyke (a), perhaps the earliest member of the Earlier Complex, is brecciated and baked at or near contacts with the ring-dykes (A) and (E), at points respectively north of Kilchoan Bay and east of Sanna Bay.

The Quartz-gabbro (c) and the Eucrite (f) are also intruded by the Quartz-gabbro (A). Further, cone-sheets of the Inner Set cutting (c) are baked in proximity to (A), which they do not penetrate. The Quartz-gabbro lettered (h) is probably later than any of the other intrusions grouped with the Earlier Ring-dykes. South of Sanna Bay, near Achosnich, an outer intrusive margin of the Great Eucrite (E) is seen against it. It may be mentioned that (E) in its turn is undoubtedly cut by two of the intrusions within it, the Quartz-dolerite (I) and the Fluxion Biotite-gabbro (k), and is earlier than perhaps all the ring-dykes which it encloses.

If we examine each intrusive complex in turn, it is found that in a general way the intrusions of the Later Complex are successively younger as we proceed inwards towards the intrusion-centre, but that in the Earlier Complex this rule is not strictly applicable.

In the Earlier Complex an aid to the determination of relative ages is the fact that while many of the ring-dykes are cut by the Inner Cone-sheets of Centre 2, some are later than them (*see* Table VII). Among those that are cut, either the Hypersthene-gabbro (a) or the Old Gabbro (b) is the oldest. The flow-banding in (a) is transgressed by the outer margin of the Quartz-dolerite (e), which also contains xenoliths of (a). Both (a) and (b) are intruded by the Quartz-gabbro (c), while (b) is also intruded by the Granophyre (c′), and internally by the Quartz-gabbro (d). Chilled margins, bearing xenocrysts of the Old Gabbro, determine the above relations of the quartz-gabbros. The Granophyre (c′) is very clearly chilled at contact with the Old Gabbro, and is also intrusive in the Quartz-gabbro (c). The relative ages of (c) and (e) cannot be directly determined. To the south, where they come nearest to one another, though still separated by (f) and (g), the Quartz-gabbro (c) seems the older, for it is full of lines of shear and contains much flinty-crush material, while the Quartz-dolerite (e) is unaffected by earth-stresses. The exact position of the short contact between (c) and (d) has not been fixed, and their relative ages have not been determined. The Quartz-gabbro (d) is only cut by a single Inner Cone-sheet, but like the Old Gabbro (b) it evidently owes its freedom from these intrusions to its central position in the complex.

The two ring-dykes (f) and (g) lying immediately within the Quartz-dolerite (e) are not cut by the Inner Cone-sheets, and though no actual truncation of a cone-sheet by a margin of these ring-dykes has been located, such truncation is practically certain in the case of the Eucrite (f). This intrusion is in turn probably earlier than its neighbour, the Quartz-gabbro (g), which presents a margin of quartz-dolerite against it at one contact noted. The Quartz-gabbro (g′) also appears to be younger than the Eucrite (f). The Quartz-gabbro (h) is intrusive against the Eucrite (f) which is baked in consequence. It also presents a chilled margin against the Quartz-gabbro (c″), and the latter, together with Inner Cone-sheets traversing it, is highly baked in the neighbourhood. The Quartz-gabbro (h) is therefore regarded as later than the Quartz-gabbros (c and c″), which are earlier than the Inner Cone-sheets, though it was not found possible in the field to fix the mutual boundary between (h) and (d). The Quartz-gabbros (g) and (h) are thus the latest intrusions belonging to the Earlier Complex. The Quartz-gabbro (h) may, however, have been wrongly grouped with the Earlier Complex, for it is possible that it is a continuation of the Quartz-gabbro (A) reappearing from below ground (*see* p. 255).

In the Later Ring-dyke Complex, the Quartz-gabbro (A) and probably also the Fluxion Gabbro (B) are earlier than the Great Eucrite (E). In the case of the Interior Complex, enclosed by and perhaps altogether later than (E), relative ages are sometimes difficult or impossible to establish. Though sharp contacts can be found between the Biotite-eucrite (G) and Inner Eucrite (H), and between the Quartz-biotite-gabbro (J) and Fluxion Biotite-gabbro (L), no direct evidence of their relative ages has been obtained. The masses (J), (J′), and (J″), being similar coarse-textured quartz-biotite-gabbros, may well be portions of one intrusion separated by the Fluxion Biotite-gabbro (L). It is therefore not unlikely that the Fluxion Biotite-gabbro (L) is later than these masses. It is at any rate certain that the narrow ring-dyke (I) is later than the intrusions which it traverses (E and G); that the Fluxion Biotite-gabbro (K) is later than the Great Eucrite (E), against which it is chilled and xenoliths of which it encloses; that the Tonalite (M) is later than the intrusions outside it, and than its elongate enclosure (J″); and that the little central mass of Quartz-monzonite (N) is later still. All these intrusions present well-chilled margins to those named as earlier.

As already stated, the recognition of adjoining masses as distinct intrusions is held to depend primarily on the observation of sharp contacts between them. In a few of the rock-masses that have been mapped out from their neighbours, no such sharp contacts have been located, but since successive intrusion can be so frequently proved in the Ardnamurchan Ring-dyke Complexes it is likely that these doubtful cases are also due to separate intrusive acts. The Biotite-eucrite (G), for example, that borders the inner margin of the Great Eucrite (E), though with difficulty separated from the Eucrite in mapping, may with reason be regarded as a separate injection and not as an inner marginal modification of the Eucrite. Along the outer margin of the Eucrite no such marginal type is found, and further, biotite-bearing intrusions are characteristic of practically the whole Interior Complex in which the Biotite-eucrite is located.

ORDER OF INTRUSION OF ROCK-TYPES AND PROBLEMS OF THEIR DIFFERENTIATION

The complete magmatic sequence of Ardnamurchan has been already stated in Chapter VIII, where the problem of differentiation has been also discussed. Here we shall add such information concerning the field occurrence of ring-dykes as may have bearing on the larger question.

It is evident that the same types of intrusive rock recur repeatedly among the ring-dykes. If we omit the rocks of the

Interior Complex, which fall into a group by themselves, we may classify the various types as (1) basic gabbros, including eucrite and hypersthene-gabbro, and (2) quartz gabbros and granophyre. Up to the Great Eucrite of Centre 3, an order of intrusion as set out below can be established, beginning with the oldest (a):—

(1) = Basic gabbros, etc. (2) = Quartz-gabbros, etc.	Intrusion-letter on Index Map, Pl. V.
(1)	a (Hypersthene-gabbro) and ? b (Old Gabbro).
(2)	c (Quartz-gabbro). c′ (Granophyre). c″, d (Quartz-gabbros). e (Quartz-dolerite veined by granophyre).
(1)	f (Eucrite).
(2)	g h A (Quartz-gabbros).
(1)	E′, E (Eucrite).

Subsequent to, and enclosed by, the Great Eucrite (E), come the intrusions of the Interior Complex. Differentiation here has followed a different course. Unlike the great majority of the preceding ring-dykes, these are all, with the exception of the Inner Eucrite (H), characterized by containing biotite in greater or less amount. So far as their relative ages have been determined, an order of increasing acidity is indicated. The Great Eucrite (E) is followed by a Fluxion Biotite-gabbro slightly less basic (K), and the period ends with the intrusion of Tonalite (M) cutting another Fluxion Biotite-gabbro (L), and lastly the intrusion of Quartz-monzonite (N).

The course taken by differentiation within the magma reservoir is to some extent indicated by a study of differentiates within individual intrusive masses. The products of such partial differentiation may be classified according to their formation (1) before the intruding magma reached its final position, (2) after movements of intrusion had ceased and while the mass was still largely fluid, and (3) after the main period of consolidation, when only a small residuum of the magma remained uncrystallized. Instances of the foregoing are cited below.

(1) Fine-grained margins of some intrusions are found to be more acid than the main body. For example, the Tonalite (M) of Centre 3 possesses a fine-grained, chilled margin of quartz-monzonite. The Hypersthene-gabbro (a) also bears in most places a very fine-grained, more acid margin, composed of quartz-dolerite. This is contrary to expectation if the rock were differentiating in place, for then the marginal and earliest crystallized portion should be, if anything, more basic than the interior. If it were not for the obviously chilled nature of these more acid margins, they might possibly be ascribed to gravitational differentiation below an

overhanging bounding wall. As it is, they seem only explicable by supposing that the intruding magma possessed a differentiated more acid upper portion which was intruded first and formed a lining to the walls of the intrusion-cavity. Similarly, along the outer margin of the Great Eucrite the normal eucrite of the interior usually passes rapidly into somewhat finer-grained quartz-gabbro that contains iron-ore in lieu of olivine, but is on the whole of eucritic aspect. Such quartz-gabbro occurs along margins against highly baked walls of basalt lava and agglomerate, as well as against older quartz-gabbro, where the occurrence gives at first sight an appearance of gradation from one mass into the other. Field-appearances support the view that the acid nature of this marginal facies is original and not due to migration of acid magma from the interior portions of the consolidating mass to the margin. The intermixture of the granophyric and gabbroid materials of the marginal quartz-gabbro is exceedingly intimate.

The heterogeneous nature internally of some intrusions may be due to partial differentiation at any stage, or to admixture of two different magmas that were simultaneously injected. In the Hypersthene-gabbro (a), masses of allivalitic gabbro and quartz-gabbro in the interior of the intrusion are found to have sharply defined mutual margins (p. 218). Their differentiation must have taken place before their final injection. Quartz-gabbros very usually contain basic portions that can only be called eucrite. The eucrite masses, on the other hand, are noticeably less variable in the field than the quartz-gabbros and hypersthene-gabbro, though differing considerably from one place to another in the relative amounts of their constituent olivine, augite, and felspar.

The Fluxion Biotite-gabbro of Sìthean Mòr, where banded with, and adjoining a mass of quartz-biotite-gabbro, seems to afford an example of intermixture (p. 330). Admixture or interpenetration of acid and basic differentiates before intrusion has been suggested by Dr. Thomas to account for various hybrid-like masses of the ring-dyke assemblage (pp. 291 and 340, and *see* p. 102).

(2) There appears to be one case in Ardnamurchan of a kind of gravitational differentiation, in the upper portion of the Quartz-gabbro (A), where it passes westwards under a roof formed of the Earlier Ring-dyke Complex. Immediately beneath this roof the rock is a basic granophyre. Downhill, the granophyre grades fairly rapidly into acid quartz-gabbro, and this gives place to normal quartz-gabbro at yet lower levels. From microscopic examination, Dr. Thomas describes the more acid, higher-level types as granophyre-gabbro hybrids (p. 287). But the amount of granophyric material decreases markedly in proportion to the depth below the roof, and it seems a case of the lighter granophyric portion of a quartz-gabbro magma having separated gravitationally from the crystallizing gabbroid portion, either subsequent to intrusion or before the magma had reached its final position. If such a separation of the granophyric portion of a quartz-gabbro magma were effected at greater depth, either distinct intrusions of granophyre might result (p. 95), or re-mixture of granophyric and

gabbroic differentiates might take place, probably giving rise to hybrids (p. 102).

(3) Residual acid magma remaining after the main consolidation of a gabbro intrusion finds its way into joints and cracks, chiefly developed in marginal portions of the mass, and forms veins. Such late differentiates suggest one possible mode of origin for the latest of the ring-dykes characterized by containing biotite, which form the Interior Complex. It is true that the veins are as a rule different in type from the rocks of the Interior Complex, for the final differentiates of the normal gabbros do not seem to produce directly biotite-bearing types. But frequently, as Dr. Thomas has found, in such acid veins as are charged with xenolithic material, or appear to have reacted on their walls, biotite and hornblende occur, and the rock-type may approximate closely to tonalite or quartz-monzonite.

Dr. Thomas has stated elsewhere his reasons for regarding the Interior Complex, that constitutes the Tonalite and Quartz-monzonite Magma-Series, as due to hybridization (p. 98). In agreement with the field evidence, he regards the postulated intermixture of the acid and basic materials as having been most completely carried out before the intrusion of the resulting hybrid. The field evidence that requires this condition is as follows :—

(1) There can be no doubt that the Interior Complex is composed of a number of distinct intrusions differing from one another in rock-type. They cannot be attributed to hybridization *in situ*.

(2) None of the masses contain xenoliths except locally, and for these xenoliths a local origin can be practically demonstrated. There is, therefore, no positive evidence that the postulated intermixture underground was between acid magma and *solidified* gabbro or eucrite. Gabbroid material involved may, however, have been xenocrystal, and all traces of megascopic xenolithic structure may have been obliterated.

(3) Fine textures are met with either as marginal facies, *e.g.* to the Fluxion Biotite-gabbro (K) and to the Tonalite (M), or as typical of a whole mass, *e.g.* the Quartz-dolerite (I). This would appear to show conclusively that the magma was in these cases at least essentially a liquid when intruded.

(4) It may be further remarked that, so far as age relations can be determined, the intrusions appear to follow one another in an orderly succession from basic to acid.

CHARACTERISTICS OF THE RING-DYKES AND THEIR BEARING ON THE PROBLEMS OF RING-DYKE INTRUSION

Crustal stresses developed in the roof of a magma-reservoir have been postulated by Mr. E. M. Anderson to account for the localization of the ring-dykes and cone-sheets of Mull around definite centres.[1] This postulate may be taken as a reasonable hypothesis, and it is now our object to set out the facts concerning the Ardnamurchan ring-dykes which are to be thereby explained.

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[1] 'Tertiary Mull Memoir,' 1924, pp. 11–12.

Perhaps the characteristic of most general interest in Ardnamurchan is the repeated shifting of the locus of igneous activity, as shown by the three main intrusion-centres that the detailed mapping has determined. The lateral shift has not been great, no more than 3 miles from the earliest centre (1) to the second, and 1½ miles from the second to the third.

The intrusion-centres are of successive ages. The intrusions belonging to each centre are also successive, and indicate prolonged periods during which the crustal stresses remained unchanged in their incidence; for, the concentricity of the intrusions belonging to the same centre is in most cases a notable feature. In ground-plan, the Earlier Ring-dyke Complex (Centre 2) appears to have been roughly circular, while the Later Complex (Centre 3), taken as a whole, possesses bilateral symmetry about an east-north-east axis, the direction towards which the shifting of the intrusion-centre took place. The diameter of each of the two ring-dyke complexes is, however, not far different, being about 4 or 5 miles. As regards the relative ages of component intrusions, there is a tendency at any rate for the Later Ring-dyke Complex to be built up from without inwards, with the older intrusions at the periphery and the younger nearer to the centre. Another feature of the ring-dykes of the Later Centre is that many of them form incomplete rings, discontinuous along the northern side of the complex.

A feature of major importance concerning the intrusion of the Later Ring-dykes is their replacement of a large portion of the Earlier Complex, and also of a great segment of the country cut by cone-sheets and agglomerate-vents. The earlier rock-masses have not been pushed to one side, as will be plain from an inspection of the Memoir-map and of Pl. II, p. 71. It will be seen that the strike of the Outer Cone-sheets of Centre 2 does not change in any way with reference to the intrusive outer edge of the Later Complex. Their orientation is evidently unaffected by the intrusion of the ring-dykes.

The annular width of ring-dykes keeps remarkably constant for each individual intrusion (*see* Pl. V). Exceptions to this rule do occur, such as the Faskadale Quartz-gabbro (A), which widens out greatly to the west, but they are, on the whole, infrequent. If we attempt to classify the Ardnamurchan ring-dykes according to their annular width, they seem to group themselves into three subdivisions:—(1) narrow ring-dykes, represented by (I), about 100 ft. wide; (2) ring-dykes of intermediate width, represented by (e), (f), (g), etc., usually about 500 to 1000 ft. wide; (3) broad ring-dykes such as (a) and (E) up to a mile in width.

Now there can be no reasonable doubt that the intrusion of a ring-dyke is preceded by ring-fracturing. The narrow ring-dyke of Quartz-dolerite veined by granophyre (I), is a good example of such a ring-fracture infilled by magma. At its north-eastern extremity, where it cuts the Great Eucrite (E), it has diminished from its usual width of some 100 ft. to only 3 ft. of breccia veined by quartz-dolerite and granophyre. The breccia consists of eucrite-like gabbro, and its clean-cut junctions with the eucrite walls are inclined outwards from the intrusion-centre of Achnaha at 70°. The breccia could not be traced farther, and this ring-fracture is therefore, so far as known, incomplete. The breccia presumably represents an initial stage in the intrusion of the ring-dyke, and it may be noted that xenoliths of eucrite-like gabbro are to be found in the ring-dyke elsewhere.

As regards the ring-dykes of intermediate width, their course is also evidently determined by ring-fissures. In the case of the Eucrite of Beinn nan Ord (f), it will be seen that it not only follows a ring-pattern but also possesses on its inner side two radially-projecting arms, which are directed towards Centre 2. It seems clear that earth-stresses must have here produced a ring-fissure with inwardly projecting radial fissures prior to the injection of the eucrite magma. Minor irregularities in the ground plan of such intrusions may be attributed to modifications of the fissure-walls by the intruding magmas or by explosive gases derived from them.

In the case of the broad ring-dykes, it would seem necessary in some instances for two parallel ring-fractures to develop and either to coalesce upwards or to become connected by cross-fracture, and so allow the country rocks between freedom to subside. The only example in Ardnamurchan of a ring-dyke with portions of a roof preserved is the Quartz-gabbro of Faskadale (A). In other cases, such as the Great Eucrite, where no original inner margin of the ring-dyke is known to have existed, a stock-like intrusion may have been formed in the first instance, and the central portion may have been subsequently cut out by a ring-fracture and replaced by succeeding ring-dyke intrusions.

The part that brecciation by explosive gases may play in the enlargement of ring-fissures is suggested by the association of vents and major intrusions in the complex of Centre 1, and by the frequent brecciation of the walls of ring-dykes belonging to Centre 2.

A striking example of a ring-dyke that has incorporated brecciated rocks similar to those forming its wall is afforded by the Quartz-dolerite of Sgùrr nam Meann. All along its outer margin against the Hypersthene-gabbro (a), the Quartz-dolerite contains xenoliths of the older rock. In fact, south of Sanna Bay, its margin is crowded with xenocrysts and shattered xenoliths resembling the shattered and contact-altered Hypersthene-gabbro alongside. The inference is that brecciation of the Hypersthene-gabbro by explosive gases was followed by the inclusion of fragments in the Quartz-dolerite magma. A ring-fissure may have been in this case enlarged by explosion, and the debris partly blown upwards to the surface as volcanic ejectamenta, and partly enclosed in the uprising magma. The Quartz-dolerite is itself almost everywhere brecciated, and its fragments re-cemented by an incoming granophyre magma (Fig. 34, p. 257). Explosive gases proceeding from the acid magma are presumably the cause of this later brecciation. The net-veining by granophyre must have led to a great increase in the volume of the ring-dyke, and the increase may possibly have been accommodated by upward movements of these igneous breccias.

Another example of an intrusive margin that is replete with xenolithic material derived from older rocks in contact, is supplied by an older Quartz-gabbro (c), next to the Old Gabbro (b). The latter is metamorphosed throughout, and is dull-black in colour, owing to the turbidity of its felspars. The same black colour characterizes the Quartz-gabbro alongside, and becomes most pronounced close to contacts with the Old Gabbro. Under the microscope, the marginal rock is found to contain a large amount of turbid felspar and altered augite, apparently as xenocrysts. It seems that here again brecciation of the Old Gabbro preceded the intrusion of the Quartz-gabbro, by which the brecciated material was enclosed. For the marginal Quartz-gabbro is definitely finer-grained than the main body, and there could not have been time after its intrusion for extensive disruption of the Old Gabbro.

Throughout this older Quartz-gabbro generally, as well as in other quartz-gabbros such as (d) and (A), a common type consists of coarse-grained acidified gabbro interspersed with fine-grained quartz-gabbro. Sometimes the coarse acidified gabbro occurs as obvious xenoliths, with sharply defined edges against the finer-grained type. It is believed that we have in such cases an old gabbro broken up and acidified by more acid magma (*see* p. 252). The localities where this variety has been chiefly noticed are in intrusions (c) and (d), on either side of the Old Gabbro (b), and in the Faskadale Quartz-gabbro (A), north of where it cuts across the Hypersthene-gabbro (a), north of Kilchoan Bay.

Still more intense brecciation affects the Eucrite of Beinn nan Ord (f), along part of its course (*see* Fig. 37, p. 266). Its component minerals are found under the microscope to have been shattered into fragments, often without losing their individual crystalline form. After brecciation, they have been reheated and so granulitized. Hot explosive gases are regarded as the cause of this phenomenon, followed by an acid magma that is now locally found as granophyre minutely veining the brecciated rocks. The gases seem to have been confined to the ring-fissure occupied by the Eucrite at the present denudation-level, and were probably derived from a more acid magma underground; for the Eucrite is brecciated along at least 2 miles of its length, while the adjacent and later Quartz-gabbro of Loch Caorach (g) is only affected in the neighbourhood of its junction with the Eucrite.

A comparison has been already made between such brecciated ring-dykes and the breccias found in the linear vent of Glas Eilean, south of Kilchoan (p., 77). To the writer, the evidence in Ardnamurchan suggests, though it cannot prove, that there is a connexion between ring-dykes and linear-vents filled with volcanic breccias, and that while the foundering of country rock *en masse* may have made room for ring-dykes in some cases, in others country rock may have been brecciated by gases derived from an intruding magma, partly ejected from volcanic orifices, and partly incorporated as xenoliths in the ring-dyke (*see* p. 75).

A stage in the infilling of ring-dyke cavities with subsequent brecciation is indicated by igneous xenoliths enclosed in ring-dykes, more especially in those belonging to Centre 2. The majority of the xenoliths, to judge from such examples as have been microscopically examined, would seem to be consanguinous to the particular intrusion enclosing them. In the Hypersthene-gabbro (a), Dr. Thomas finds that hypersthene-bearing granulites are prevalent. In the Quartz-gabbro (A), fine-grained quartz-gabbro occurs locally as xenoliths. In the Eucrite of Beinn nan Ord (f), and occasionally in the Great Eucrite (E), fine-grained olivine-rich eucritic types are found. There is a resemblance between such cognate xenoliths and the fine-grained margins of the enveloping intrusion. For example, they are mostly non-porphyritic in the Hypersthene-gabbro of which the fine-grained margins are also non-porphyritic; while porphyritic xenolithic strips are found in the southern part of the Great Eucrite, and in this instance, porphyritic fine-grained gabbro occurs around its southern edge, which probably forms part of an early chilled margin. So it seems as if the first influx of magma into ring-fissure or ring-cavity became quickly consolidated, and was broken up and incorporated as xenoliths in the subsequent intrusion of the main mass. Such accidental xenoliths as occur, usually resemble the cone-sheets, or, less often, basalt lava.

Brecciation due to crustal stresses is met with occasionally. The linear arrangement of such crushed material, and its association with black flinty crush-rock, distinguish it from the brecciation that is attributed to explosion. The Quartz-gabbro (c) affords a striking example of such crushing, which was effected during the Earlier Ring-dyke period. In this case the gabbro, where it is much sheared and traversed by bands of flinty-crush, is cut by minor intrusions, including Inner Cone-sheets, which are quite uncrushed but have suffered baking. These minor intrusions are earlier than the adjoining Beinn nan Ord Eucrite (f), to which their contact alteration would appear to be due. Possibly the marginal flinty crush-rock developed in this old Quartz-gabbro may be the result of cauldron-subsidence. If so, the centrally sunken block may have included also the Granophyre (c′), the Old Gabbro (b), and the Quartz-gabbros (c″) and (d). The sheared margin of this block is, however, only seen in two places, at the north and south ends of the Beinn nan Ord ridge. Elsewhere, if it once existed, it may have been obliterated by younger intrusions.

In conclusion, it is noteworthy that ring-dyke fissures must have been formed again and again in Ardnamurchan, and that such fissures have nowhere been detected unfilled by magma. Unlike the cone-sheet fissures, they would seem to have been accompanied in all cases by magmatic intrusion. J.E.R.

CHAPTER XVI

TERTIARY RING-DYKES OF CENTRE 2, ARDNAMURCHAN

An early complex of ring-dykes situated in the south-west part of Ardnamurchan and referable to Centre 2 is indicated chiefly by the mapping (*cf.* Pls. II and V). The ring-dykes composing this complex are transgressed by the outer margins of two outer ring-dykes of Centre 3, the Quartz-gabbro (A) and the Great Eucrite (E), and there is evidence at contacts of the intrusive nature of these margins. The reference of the Earlier Ring-dykes to the same centre (2) as the majority of the cone-sheets is best indicated by the curving outcrops of the Hypersthene-gabbro (a) and the Old Gabbro (b). The intrusive outer margin of the Hypersthene-gabbro is partly hidden beneath the sea, more especially at Sanna Bay, but is sufficiently complete to show its conformation to Centre 2. It should be added that the two portions of this intrusion separated by Sanna Bay undoubtedly belong to the same ring-dyke, for they are alike in rock-type, which is peculiar to them, and also in having similar fine-grained outer margins of quartz-dolerite. In the case of the Old Gabbro, its margins are largely determined by the contacts of later intrusions, but a portion of its inner wall against older rocks is preserved and indicates a curve of which the centre approximates closely to Centre 2. Other intrusions such as the three narrow, slightly curving, ring-dykes, the Quartz-dolerite (e), Eucrite (f), and Quartz-gabbro (g), immediately within the Hypersthene-gabbro, afford confirmatory evidence, while of still greater significance is the recurrence of cone-sheet intrusion around Centre 2 (Inner Cone-sheets) during the Earlier Ring-dyke period.

The order in which the various ring-dykes of Centre 2 will be described is, so far as can be determined, their order of intrusion (*see* Table VII, p. 201). The relative ages of some ring-dykes cannot be fixed, though all can be satisfactorily placed in one of two time-groups dated with reference to the Inner Cone-sheets, with the exception perhaps of the Quartz-gabbro of Aodann (d). It has not been found possible in the field to separate this mass from the Quartz-gabbro of Beinn Bhuidhe (h), which is younger than the Inner Cone-sheets, but it is unlikely that they are the same intrusion. The Aodann mass (d) is only cut by one cone-sheet, but may well owe its almost complete freedom from sheets to its central position relatively to the Inner Cone-sheet belt, as is true also of the still earlier Old Gabbro (b) within which the Aodann Quartz-gabbro is situated.

The intrusions to be described in the present chapter are:—(*a*) Hypersthene-gabbro of Ardnamurchan Point; (*b*) Old Gabbro of Lochan an Aodainn.

(*a*) HYPERSTHENE-GABBRO OF ARDNAMURCHAN POINT

This intrusion is the outermost and largest, perhaps also the earliest, of those belonging to the Earlier Ring-dyke Complex. It forms the nose of the Ardnamurchan peninsula and there occupies somewhat remote country, but it also extends eastwards to the neighbourhood of Kilchoan, where it is within easy access.

The chief importance of this ring-dyke, as already mentioned, lies in the fact that it is the most completely preserved of all those belonging to the Earlier Complex, and thus best demonstrates their conformation to Centre 2. Another point that it serves to prove is that there are cone-sheets of different ages to be referred to this Intrusion-Centre, for it is clearly later than the vast majority of cone-sheets traversing its outer wall, while it is itself cut, along its inner margin, by the Inner Cone-sheets (Fig. 35, p. 259).

A characteristic of the mass, which may be specially referred to here, is its exceptionally wide fine-grained outer margin. Notwithstanding this evidence of relatively rapid marginal consolidation, the intrusion has intensely altered the surrounding country rocks. Another feature of interest is the abundance of xenolithic basic igneous material of fine texture, often in the form of strips or bands that are parallel to adjacent margins of the intrusion and also to flow-banding in the gabbro. So far as this material has been examined microscopically, it is found to be mostly akin in composition to the Hypersthene-gabbro itself. It probably originated as an early injection into the ring cavity, which was broken up and incorporated by the main intruding mass. The elongate strip-like form must be largely original, due to some process of scaling off from the sides of the intrusion-cavity, but it is also in part the result of the streaking-out of the xenolithic rock when in a plastic state.

The typical rock is a pyroxene-rich gabbro, of uniform greyish-brown colour on weathered surfaces, a contrast to the speckled aspect of the eucrites and of many quartz-gabbros. Under the microscope (p. 223), hypersthene is almost invariably found to be present, and though this mineral is often met with in other Ardnamurchan gabbros as an original constituent, it is never, in such cases, of general occurrence, and is rarely conspicuous in amount.

Locally, more basic and also more acid types are met with, usually associated in patchy fashion with the normal type, but sometimes as distinct masses. The more basic types are olivine-rich, and may be termed eucrites (*22666*); the more acid are quartz-gabbros (*23616* and *23622*). Both types contain hypersthene, thus showing their affinity to the normal rock. A locality where eucrite occurs in considerable amount is south of the Lighthouse, about 150 yds. inland from Port Min. The quartz-gabbro type is a feature of the more immediate neighbourhood of the Lighthouse. Near Kilchoan this type is also seen, for example, in a road-metal pit at a sharp bend in the Achnaha road, 600 yds. north-west of the Free Church. Felspathic quartz-gabbroid portions are there associated with more basic pyroxene-rich portions.

Where these variant types form considerable individual masses, sharp junctions between them and the normal gabbro have been noted. About 600 yds. east of Port Mìn felspathic quartz-gabbro is thus related to the normal hypersthene-gabbro. Again, south-east of Beinn nan Ord, 250 yds. south-east of a small loch, there is a small mass of the eucritic variety in sharp contact with a less basic type (22674). On a steep rock-surface facing south this junction is seen for many yards, and is conspicuous at a distance owing to the colour-contrast between the two rocks. At another point of contact the less basic gabbro is fluxioned, as though the eucrite had solidified first. The above examples indicate that differentiation of the Hypersthene-gabbro magma had taken place to a certain extent previous to its final intrusion. Variant types do not, however, form more than a small fraction of the whole mass.

Marginal Facies. Towards its outer margin, as already stated, the Hypersthene-gabbro becomes much finer grained, and iron-ore is especially characteristic of this portion of the intrusion. This mineral is plentiful, for example, at exposures east of the road leading from Kilchoan to Achnaha and Achosnich, 300 yds. north-west of the Free Church. At its extreme outer margin the rock as a rule is a quartz-dolerite, and consequently more acid than the main mass. This marginal variation is perhaps best seen on the rocky northern coast, east-north-east of Plocaig, where the mass is in contact with the Outer Cone-sheet Complex. Though the cone-sheets are highly granulitized, they are a little difficult to distinguish from the marginal gabbro which is of similar texture. The latter, however, weathers brown in colour, rather than grey, which is the tint of the baked rocks, or else shows the pale, blotchy weathering typical of quartz-dolerite. The marginal rock passes very gradually into coarse-grained normal gabbro internally. Such more acid margins are a recurring feature of the ring-dyke intrusions, and in the present instance, and also in the case of the Tonalite (p. 337), they are definitely chilled. Their probable significance has been already discussed (p. 209).

Another characteristic of the outer margin is a profusion of acid veins, usually not exceeding a few inches in thickness, with which also the bounding wall is sometimes intricately injected. The acid magma concerned was evidently a late product of the crystallization of the mass, and need not necessarily have been derived from the early-crystallized quartz-dolerite margin. The latter consolidated as a definite rock-type and was subsequently veined by acid magma that may have been derived from another portion of the intrusion. The rock of the veins is sometimes a monzonitic type (21524, 21812), due to the incorporation of previously consolidated gabbroic material (*see* p. 211).

MARGINAL RELATIONS

The outer margin against the earlier bedded rocks that are cut by cone-sheets is continuously preserved on the south side of the intrusion. To west and north, sufficient of this margin has escaped erosion by the sea to demonstrate its curved outline conforming to the Aodann Intrusion-Centre (2). To the east, the course of the intrusion is interrupted by the Later Ring-dykes belonging to Centre 3, and it is therefore not known whether it originally formed a complete ring.

Along its inner margin it is everywhere in contact with later intrusions, and no portion of its original inner wall is preserved. There is, however, evidence of an inner marginal facies close to such contacts. It is therefore concluded that the intrusion in its original form was a ring-dyke, and not a stock of which the central portion has been displaced by later intrusions. Even as a ring-dyke it is of massive proportions, its annular width being about two thirds of a mile, and its external diameter about $4\frac{1}{2}$ miles.

Outer Margin.—In the vertical direction, only a few hundred feet of the outer southern margin of the gabbro is seen. A steep outward inclination is so far demonstrable. Along the inner margin, as will be described later, internal structures such as flow-banding point as a rule to its inclination being steeply inwards. Consequently, we may conclude that the intrusion has steep sides converging upwards. No roof is, however, actually known, unless possibly north of Kilchoan, where basalt lavas on the Glebe Hill, at an altitude of about 150 ft., seem to overlie the gabbro, which is exposed in valleys on either side. If so, the gabbro must be plunging steeply eastwards under roof in this neighbourhood. For immediately to the west of the Glebe Hill, on the lower eastern slopes of Beinn na Seilg, the gabbro is found at a higher level than the supposed roof. On these slopes the outer margin is transgressive and steep, running straight uphill from a point at about 300 ft. to the 700-ft. contour.

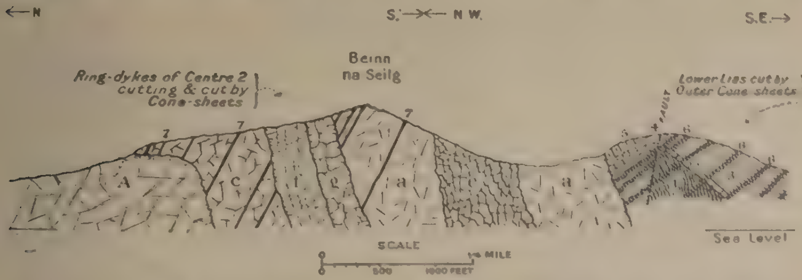
←N
S.→←N.W.
S.E.→
Beinn na Seilg
Ring-dykes of Centre 2 cutting & cut by Cone-sheets
Lower Lias cut by Outer Cone sheets
Fault
7
7
7
5
4
6
A
c
f
g
a
e
a
Sea Level
SCALE
0
500
1000 FEET
¼ MILE

FIG. 28.—*Section across south-west part of Ardnamurchan Igneous Complex.*

1, *Highland Schists.* 2, *Trias.* 3, *Lias.* 4, *Inferior Oolite (limestone and sandstone).* 5, *Tertiary basalt lavas.* 6, *Outer*, and 7, *Inner*, *Cone-sheets of Centre 2.* *Ring-dykes* a, c, e, f, g, and A *as lettered on Plate V., p. 201.*

Farther west, south-east of Beinn na Seilg, the twin lochs (Lochain Ghleann Locha) lie in a hollow along the margin of the gabbro, which is bounded by basalt lavas that form steep crags. From this point the margin continues westwards, crossing the summits of hills and ridges that slope steeply southwards towards the sea, and extending southwards for short distances obliquely down the intersecting valleys. A general southerly, *i.e.* outward, inclination of the margin is thus suggested, and this is confirmed by an observed inclination in a much deeper section where the gabbro margin reaches the coast, on the west side of Beinn nan Codhan. The margin there extends, in a horizontal distance of about 500 ft., from the top of a cliff, 400 ft. high, obliquely down to sea-level.

North-west of Beinn nan Codhan, along the western side of the gabbro, there occur within the mass two outcrops of highly granulitized rocks. These consist mainly of baked shale, presumably belonging to the Lower Lias, together with some amygdaloidal basaltic rocks, presumably lavas. It is possible also to detect basic intrusive sheets running north-west, which are interpreted as cone-sheets (p. 180). The junction between the larger outcrop and the gabbro on its inner side is steep, as is plainly seen at its south-east end. The two outcrops appear to be portions of a screen separating the main mass of the Hypersthene-gabbro from an outer arm. The latter forms the ridge of Garbhlach Mhòr, where the gabbro is fine grained and contains plentiful iron-ore. At the north-west end of this ridge, highly baked shales (? Lower Lias) occur at the top of a sea-cliff, and probably form part of the outer wall of the intrusion. The shore below was found unreachable from the landward side, and whether the shales actually extend to there, as mapped, from the cliff summit, is not certain. The curving coast-line around the west side of Garbhlach Mhòr, however, must closely approximate to the outer margin. Farther north, along the shore west of the Lighthouse, the gabbro becomes very fine-grained and assumes the quartz-dolerite facies found in most places along its extreme outer margin. It may thus be inferred that this locality is only a very short way from the actual outer edge of the mass.

Along the rocky, northern side of Sanna Point, the marginal quartz-dolerite facies is again met with. Just east of this, the country rocks, comprising Mesozoic sandstone and limestone profusely intruded by cone-sheets, are seen once more, and form the headland of Rudha an Dùin Bhàin (*see* one-inch Sheet 51). These rocks are so intensely baked that the chilled edges of the cone-sheets are seldom discernible, but shreds of sediment that occur at intervals show that we are dealing here with a portion of the cone-sheet complex. A steep junction of the gabbro with this complex is on view in the sea-cliff, which is about 20 ft. high, 300 yds. west-south-west of the headland. From this point the margin extends eastwards, and runs out to sea again north of Plocaig. Half a mile east-north-east of Plocaig it turns inland once more, where the customary quartz-dolerite marginal facies is presented against the cone-sheet complex. The margin is again seen a short way inland to the south, on the east side of a hollow that marks a north-west crush-line. Nearby, the Hypersthene-gabbro ends against the Great Eucrite Ring-dyke that belongs to the Later Complex.

Inner Margin.—As already mentioned, the original inner margin of the Hypersthene-gabbro nowhere exists, for on its inner side the intrusion is everywhere in contact with younger ring-dykes.

Remnants of an inner marginal facies may, however, be recognized in certain banded and fluxioned varieties of the Hypersthene-gabbro. Banded structure is especially well developed in the vicinity of Beinn na Seilg, as, for example, on a more southerly peak of that hill, marked on the Memoir-map by an Ordnance Survey cairn. The bands there incline northwards at angles of 35 to 45 degrees. Westwards, as far as the south-east end of Beinn nan Ord, similar inclinations are found. But eastwards, on a rocky summit east of the southerly peak, the banding is flat or only slightly inclined northwards. The banding, if due to flow-movements near margins, must be connected with a roof, where flat, or else an inner margin, not the outer, since it is separated from the outer margin by a wide outcrop of unbanded gabbro. The evidence, then, suggests an inward northerly inclination for the inner margin between Beinn na Seilg and Beinn nan Ord, and a flat roof eastwards of Beinn na Seilg. Farther east, on the Glebe Hill, at a much lower level, the intrusion appears to be overlain by roof, as already described (p. 219).

East of Druim Reidh-dhalach, 150 yds. south-west of two adjoining lochs (Lochain Dubha), the inner junction against the Quartz-dolerite Ring-dyke (e) runs close to a hollow, along which the Hypersthene-gabbro is very fine grained and rich in iron-ore. When traced away from this margin, up the slope of Druim Reidh-dhalach, the gabbro grades into the normal coarse-grained type.

Farther north-west, fluxion gabbro, with sharply defined felspar plates in parallel orientation, occurs all along the inner margin, from where an outlying mass of the Hypersthene-gabbro is surrounded by the later Quartz-dolerite northwards to the coast, east of the Lighthouse. The observed inclinations of fluxion are consistently eastwards at high angles of about 70 degrees. Similar fluxion gabbro is often met with elsewhere in the ring-dyke complex, either as marginal fringes to gabbro and eucrite intrusions, or as individual intrusive masses. In the present case the fluxion type is marginal, for its gradation into the normal hypersthene-gabbro of the interior is evident. Alternating belts of the two types occur along the inner margin east of the Lighthouse, on the right side of a stream that enters the sea east of the Lighthouse pier, and south of a patch of raised-beach deposits.

The inclination of fluxion eastwards of the Lighthouse, then, suggests a steep inclination of the inner gabbro margin inwards and eastwards towards the Intrusion-Centre of Aodann. Other evidence of this from the vicinity will be stated below.

XENOLITHIC INCLUSIONS

Xenoliths are very common, and sometimes abundant. In their present condition they may be described as basic granulites. Originally, as the microscope shows, their rock-types were various. Fine-grained hypersthene-gabbro is most common (23633), which is apparently consanguinous with the intrusion itself. Other types identified by Dr. Thomas are olivine-gabbro (22667), porphyritic gabbro (22631) with its felspar phenocrysts plainly seen in the field to have been drawn out by flow-movement (Eilean Carrach), and quartz-dolerite of cone-sheet type (22278). The xenoliths occur as irregular masses, or angular fragments, or else as elongate bands. Contacts with the enclosing gabbro are in general perfectly sharp, and there is seldom any sign of absorption by the gabbro magma. The xenolithic bands or strips are of much interest. They are very numerous, for example, along the banded inner margin on Beinn na Seilg, and may be conveniently examined on the rocky summit east of the south peak and north of the twin lochs (Lochain Ghleann Locha). The bands are a foot or so across and keep a constant width for several yards ; they are here either flat or else gently inclined northwards. At first sight, indeed, they look like basic intrusive sheets in the gabbro, and usually their minute felspars are orientated parallel to the surface of the band, as though arranged by flow-movement. But on closer examination it is found that their margins are quite unchilled and are, indeed, interbanded with coarser gabbroic material, as though these margins were viscous and were subjected to slight intermixture and flow-movement with gabbro-magma in contact. This opinion is confirmed by the fact that the xenolithic sheets are arranged parallel to the flow-banding in the surrounding gabbro and follow its changes of direction. Further, they, in common with the gabbro, are traversed by acid veinings due to a residual acid portion of the gabbro magma. Another good locality for xenolithic sheets is between Garbhlach Mhòr and the Lighthouse, near to the outer margin of the intrusion. The xenolithic sheets are consistently inclined to the north of east at 60 degrees, and in direction they are parallel to the course of the ring-dyke. Their degree of inclination may well be a measure of the inclination of the wall at this point in its course. If so, the local inclination is inwards. The gabbro is also characterized hereabouts by close-set joints that are parallel to the xenolithic sheets. The joints are to be attributed to the contraction of the gabbro mass on solidifying, and are presumably parallel to the gabbro margin. The xenolithic sheets range up to 20 ft. in width, but are more usually about 4 ft. They have perhaps been drawn out to some extent by flow-movement when in a plastic condition, for a platy structure parallel to their surface is very marked. The thicker individuals can be traced for 50 yds. and upwards along the rocky headland of Dubh Rudha Mòr, north of Port Mìn.

Interesting xenoliths of sapphire-spinel rock are associated with highly granulitized fine-grained gabbro at the outer margin of the Hypersthene-gabbro just north of Glebe Hill. They are described in detail below (p. 233).

AGE RELATIONS

The Hypersthene-gabbro is younger than the Outer Set of Cone-sheets, and older than at any rate the great majority of the ring-dykes.

The relations to the Outer Cone-sheets have already been fully discussed (p. 182), while along its inner margin the Hypersthene-gabbro is everywhere in contact with ring-dykes younger than itself, as will be described under the various later intrusions concerned (*see* Table VII, p. 201). The only important ring-dyke of the Earlier Complex with which age relations cannot be established is the Old Gabbro (b) of Lochan an Aodainn. Both of these intrusions are, however, of early date, and lithologically they have points of resemblance, both being usually pyroxene-rich gabbros. The Old Gabbro is therefore described next. J.E.R.

PETROLOGY OF HYPERSTHENE-GABBRO

(Anal. II, Table IV, p. 85)

Normal Types.—The gabbro that constitutes the outermost member of the ring-dyke complex of Centre 2 is a slightly variable rock as regards composition and texture, but on the whole shows a remarkable consistency in its mineral assemblage. The mass is characterized by the general prevalence of a rhombic pyroxene (hypersthene) in sufficient quantity to entitle the rock to the name hypersthene-gabbro or hypersthene-eucrite. In this respect it differs from most of the Tertiary gabbros of Britain, for, while they frequently contain rhombic pyroxenes, such minerals usually fall within the category of accessory constituents, and do not appear to play an essential part in the rock's constitution.

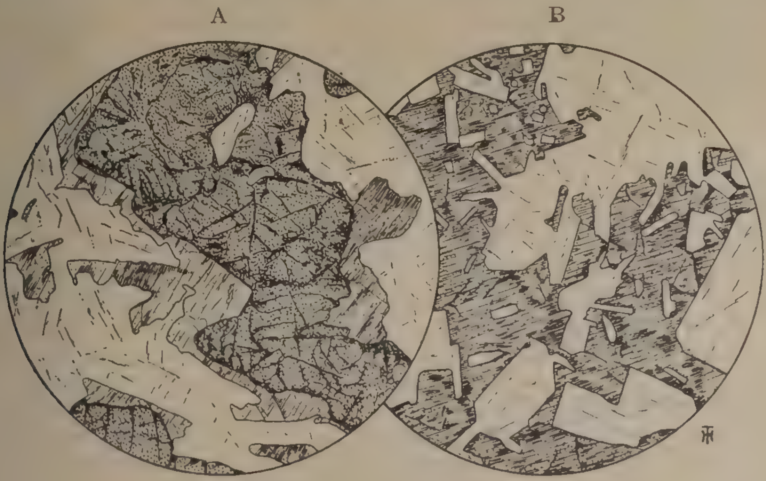

FIG. 29.—*Hypersthene-gabbro.*

A. (23625)×20. *Hypersthene-gabbro. Large crystals of olivine fringed with hypersthene and embedded in a matrix of basic plagioclase felspar.*

B. (22376)×20. *Olivine-free variety of the Hypersthene-gabbro showing ophitic relations of hypersthene and labradorite.*

In the hand-specimen the rock shows some textural variation. Usually it is a moderately compact rock of a medium to dark-grey colour, with its light and dark minerals in about equal proportions collected into areas measuring a quarter of an inch or so across.

The coarseness, however, varies gradually from place to place without apparent plan, and occasionally the rock may become so coarse that individual crystals reach several inches in greatest dimension.

Microscopic examination of a number of specimens selected from the interior of the intrusion, along the length of its outcrop, demonstrates the general basic nature of the mass, which is composed of olivine, hypersthene, augite, and a basic plagioclase felspar. Accessory minerals such as iron-ore and apatite are most often either poorly represented or absent, but iron-ore on occasions shows segregation into well-defined patches.

As might be expected, in addition to textural variation, there is considerable variation in the relative abundance of the respective mineral constituents. In some parts olivine occurs in profusion and rhombic pyroxene is poorly represented ; elsewhere hypersthene is more abundant than olivine, while in most other cases these two minerals occur in approximately equal proportions. Thus some portions of the mass might be referred to as olivine-gabbro with subordinate hypersthene, and others as hypersthene-gabbro with subordinate olivine. It is, of course, not unusual to find some sort of interdependence between these two minerals in rocks of gabbroic composition, especially where there is a tendency for some parts of the mass in question to pass into rocks referable to the quartz-gabbros, by the development of an interstitial acid residuum.

In the normal rock, olivine is usually in excess of rhombic pyroxene. It is a colourless variety occurring in rounded or sub-idiomorphic grains and crystals reaching a millimetre or so in diameter, or forming glomero-porphyritic groups two or three times this size (22388). Generally it is in a fresh condition, but when pseudomorphed it gives rise to so much finely divided magnetite (22666) that the pseudomorphs are rendered almost opaque. This fact leads to the assumption that the olivine is a variety fairly rich in iron, a surmise strengthened by the optically negative character of the mineral. It is generally quite definitely the earliest product of consolidation, behaving poecilitically towards late-formed pyroxenes and felspar (21506), and seldom showing simultaneous crystallization with any other constituent.

Hypersthene is the usual rhombic pyroxene, and occurs commonly in close association with olivine (21589). It is strongly pleochroic in shades of pink and green, and is frequently associated with a little biotite with or without attendant iron-ore.

The felspars are for the most part somewhat small crystals, much twinned and zoned, which form interlocking and mutually interfering aggregates. The zoning of felspars is a common feature of the normal gabbros and less basic eucrites, but is less common in the more basic eucrites and peridotites (allivalites, etc.). The felspars of the Hypersthene-gabbro cover a fairly wide range in composition. Initially they are mostly a basic labradorite or bytownite, optically negative in character. Commonly the zoning by less basic species is more or less peripheral, and oligoclase when present forms but a thin and almost negligible ultimate layer on the earlier, more basic, individuals. All the same, this zoning of the felspar is sufficiently pronounced to give the completed crystals a bulk-composition of normal labradorite.

The monoclinic pyroxene is a normal aluminous augite, and is an invariable constituent of the gabbro. It occurs in fair quantity and is always ophitically related to the felspar or poeciliticallv to olivine. Usually it has a greenish tint, but shows no pleochroism. A diallagic structure is often absent, but at other times it may affect the whole or part of an individual crystal.

Of the rocks more than usually rich in olivine, that represented by the analysis given on p. 85 and collected from the south-west of Beinn na Seilg may be regarded as typical. Other examples may be noted from Beinn nan Codhan and the neighbourhood of Ardnamurchan Point.

The analysed rock (22821) contains the usual ferriferous olivine in rounded crystals and grains, associated with a small amount of hypersthene and enclosed in a coarse mass of ophitically related augite and basic labradorite. The augite exhibits schillerization and shows local corrosion, presumably by acid final products of consolidation.

Very beautiful examples of the olivine-rich variety occur in the neighbourhood of Beinn nan Codhan (23624–5). Their more definitely eucritic nature is shown not only by the abundance of olivine but by much of the felspar having an optically negative sign. The olivine when decomposed yields the usual magnetite-rich pseudomorphs (23624), and the hypersthene where altered passes into fibrous actinolitic hornblende. Towards Ardnamurchan Point occur similar basic types that carry much fresh olivine. In some instances (21552) they show the unusual feature of having their olivine in part moulded upon an early generation of basic felspar, while others show a slight segregation of iron-ore following on the crystallization of olivine (23619), which mineral, together with some felspar, is included poeciliticallv.

In yet another variety of the gabbro, hypersthene is abnormally abundant and, like the augite, builds large masses that behave ophitically towards the larger felspars (21500, 22272), and often enclose a host of smaller individuals in poecilitic fashion (22376). The hypersthene shows the usual pleochroism and often exhibits a schiller-structure.

A somewhat fine-grained type, extremely rich in hypersthene and relatively poor in olivine, with local segregation of iron-ore, comes from the north-west end of Druim Reidh-dhalach to the south-east of Ardnamurchan Point (23618).

To the east of Sanna, in the neighbourhood of Plocaig, on the north coast, the gabbro is mainly of the olivine-rich variety (22264, 22266) but locally contains abundant strongly pleochroic hypersthene (21550). In this portion of its outcrop it is in contact with the Great Eucrite of Centre 3, and the schillerization and turbidity of its felspars (22265, 21550) suggest that it has to some extent been affected by metamorphism brought about by the later intrusion.

Marginal Facies.—A feature of the Hypersthene-gabbro is an outer marginal facies that is finer in texture, and in bulk-composition considerably less basic, than the main part of the intrusion. The rocks in this marginal portion of the mass, though frequently veined by later acid material, do not in themselves show a macroscopic patchy development of acid and basic material such as is a feature of basic rocks that have been permeated by a later and more acid magma. They have the appearance in the field of more or less normal quartz-gabbros and quartz-dolerites. The microscope, however, reveals the fact that on a microscopic scale we have in reality basic material involved and enveloped by an acid magma, or partial magma, that has disturbed the original set of equilibria, and brought about recrystallization and mineralogical adjustments. In some cases these are so extreme and so evidently connected with the migration of acid matter that the processes involved are akin to those of hybridization. At the same time it is impossible to connect this acidification, or abnormally acid character of the marginal portion of the gabbro, with any definitely later intrusion of acid magma, and we are forced to the conclusion that it has been produced by a partial magma for which the Hypersthene-gabbro is alone responsible.

In the rocks of this marginal zone olivine or its pseudomorphs are entirely wanting, and thus it would appear that the original rock was less basic than the normal gabbro of the interior of the mass.

As exemplified by a number of specimens collected mainly in the neighbourhood of Ardnamurchan and Sanna Points, the rocks are composed of augite, plagioclase felspar, rhombic pyroxene, and iron-ore in varying proportions, with an irregularly distributed base of alkali-felspar and quartz.

The augite appears to be for the most part an original constituent and, where least affected by contiguous acid material, is a brownish variety that occurs in coarsely ophitic relationship with moderately basic labradorite felspars, after the manner of augite in the normal dolerites or olivine-free gabbros. It usually has a pronounced diallagic structure that has contributed largely to its turbidity and general brown colour. The original felspars are fairly large zoned individuals of labradorite. Hypersthene appears to have been a universal constituent, and in some cases still exists in a fresh condition (23622). Generally, however, the rhombic pyroxene is now represented by pseudomorphs, in fibrous hornblende and other decomposition products, which show that the individuals reached considerable dimensions and, like the augites, were often ophitically related to the original felspars (22269 and 22269 A). Iron-ore is a moderately abundant constituent (23615, 22271) and in certain cases builds large plates referable to ilmenite (22270). In their original condition, therefore, the rocks were probably olivine-free hypersthene dolerites or gabbros.

The outstanding character, however, of these marginal types is their microscopic permeation by an apatite-rich acid partial magma that has reacted upon, and modified to a varying degree, the original constituents. The amount of acid material present in any section is far from constant, here collecting into small insignificant areas, and there reducing the rock to an almost granophyric condition (23614). The acid material itself has invariably solidified as a micrographic growth of alkali-felspar and quartz which is charged with needles of apatite, a mineral that is poorly represented in the normal dolerites and gabbros of Ardnamurchan.

In addition to permeating the rocks in the form of granophyric matter this acid material has been able to react upon the original minerals and marked changes are to be noted, particularly in the augite and early felspars. The augite assumes a patchy appearance due largely to resorption, the local obliteration of the original schiller structure, and the regrowth of a greenish unschillered augite that encloses small grains of magnetite and flakes of biotite (23615). At the same time, the original ophitic structure is to some extent destroyed and the boundaries of the crystals rendered less definite and regular. The felspars exhibit the effects of marked resorption and a general acidification. Felspars, or parts of felspar crystals, that have escaped the processes of resorption and acidified regrowth, either show a characteristic turbidity and schillerization (23614, 22271) or have suffered albitization (22270). Almost all felspars in those rocks that contain much micrographic matter have suffered resorption and regrowth with less basic varieties that range to oligoclase-albite in composition (21558). In the regrown portion of the felspars it is not uncommon to find needles of apatite, a mineral essentially a product of the partial magma, and in one instance a group of blue tourmaline needles, indicating the active presence of mineralizers, has been detected in a similar position.

On and near its inner margin the Hypersthene-gabbro shows a similar type of acidification to that encountered in the outer marginal zone, but in addition is characterized by a fluxional arrangement of its constituents. Augites are deschillerized with the microscopic crystallization of magnetite and biotite within their boundaries, and old felspars are albitized, shattered, and regrown (23621). Possibly the rock has been affected in some measure by the adjacent later Quartz-dolerite Ring-dyke (e).

A representative of the Hypersthene-gabbro, more than usually rich in iron-ore, occurs near the inner margin of the intrusion, 700 yds. southward of Loch Caorach (21517). It is a somewhat abnormal granulitic doleritic type, consisting mainly of ophitic to granular diallagic augite, intimately intergrown with magnetite that forms perhaps 10 to 20 per cent. of the mass, and labradorite felspar as somewhat small twinned crystals.

Acid Veins.—The acid veins (p. 218) that characteristically cut the outer margin of the gabbro and often pierce its bounding wall represent a late migration of acid magma that was the final product of consolidation of the gabbro mass. They have compositional similarity to the acid patches described above, but are related to the gabbro in the same way as fine textured aplitic veins are related to many of the larger granitic intrusions. In their least contaminated form they were either granophyric or aplitic in character (23616), but in almost every case they have been basified to some extent by the complete or partial assimilation of basic material. Where relatively unmodified, they consist of somewhat stumpy crystals of oligoclase-albite felspars distributed through a mosaic of perthitic alkali-felspar and quartz, which carries moderately abundant apatite (21524). The oligoclase crystals have an average length of about half a millimetre and are two or three times as long as broad. They are usually turbid but show traces of lamellar twinning. Quartz is abundant and has quite irregular form. Although often not in obvious micrographic intergrowth with alkali-felspar, adjacent areas of quartz have simultaneous extinction and thus a granophyric structure is indicated.

In other cases a fine granophyric matrix is the rule. Contamination by partial assimilation is to be inferred by the occurrence of occasional undissolved patches of augite and iron-ore of gabbroic or doleritic origin, and remnants of modified basic felspars derived from a similar or identical source. It appears almost certain that all the augite encountered in these rocks is xenocrystal in character.

The effects of more complete assimilation of basic material are to be noted in the crystallization throughout the rock of a greenish hornblende, often intergrown with, or fringing, the xenocrystal augites; patches of biotite; and a rhombic pyroxene, frequently in well-shaped crystals but usually pseudomorphed. In other cases the rocks are replete with undigested basic material in the form of augite, iron-ore, and basic plagioclase, of gabbro derivation. Augitic clots have generally given rise to areas rich in well-crystallized greenish hornblende (21520), while the matrix carries hornblende, biotite, and rhombic pyroxene, as the results of more complete assimilation.

Sometimes the more basic felspars are edged with perthitic orthoclase and surrounded by micropegmatite (21812). On occasions, when these veins carry an unusual amount of xenolithic basic material, there has been a widespread crystallization of rhombic pyroxene (hypersthene) in small crystals and grains as the result of acidification (21522).

It will be seen that many of these rocks reproduce the character of gabbro-granophyre hybrids in the production of a pyrogenetic hornblende and rhombic pyroxene, and, in a measure, recall the mineralogical associations met with in the Tonalite and Quartz-monzonite of the Interior Complex of Centre 3 (pp. 338, 341).

A remarkable type in the outer marginal zone of the Hypersthene-gabbro is a pyroxenic rock abundantly rich in a peculiar augite (Fig. 30 B). It is dark grey-green in colour, finely crystalline in aspect, and carries crystals of sphene visible to the unaided eye. The augite builds mutually interfering, somewhat elongated, crystals of a dirty brownish-green colour with an occasional tinge of olive-green. It is strongly pleochroic in tones of olive-green and bright yellow-brown and is comparable in most respects to the augite described from the so-called Augite-diorite of Camphouse (p. 153). The other constituents are subordinate in amount and consist of labradorite felspar, in small elongated crystals ophitically enclosed by the augite, occasional scattered granules of magnetite, and a few large patches of pale brownish sphene. Apatite is represented by a small number of somewhat large turbid crystals.

The rock carries locally an acid mesostasis that consists mainly of feathery aggregates of alkali-felspar, but contains abundant minute acicular prisms and grains of augite, needles of apatite, and finely divided magnetite. This acid matter is out of sympathy with the rest of the rock, and has produced marginal resorption of the larger augites and acidification of the felspar.

The rock as a whole is presumably a basic band, or granulite, in the Hypersthene-gabbro which has suffered hybridization by acid emanations from the surrounding intrusion. It is so similar to the Camphouse Augite-diorite, the hybridized cone-sheets lying to the south-east of Rudha Groulin (22636, p. 155), and the Hypersthene-gabbro itself on the shore west of Sanna where hybridized by acid emanations from the Great Eucrite (p. 311), that it must have had a similar origin.

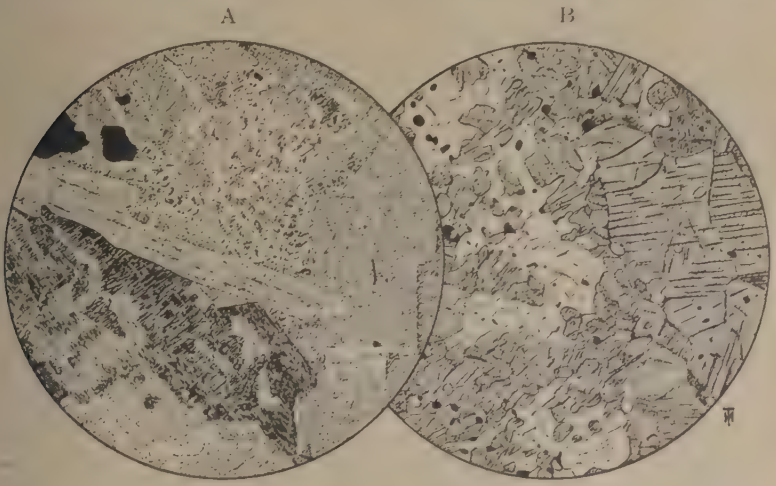

FIG. 30.—*Acidification of Hypersthene-gabbro.*

A. (21522)×20. *Acidified gabbro. The section shows partly resorbed augite, plagioclase felspars albitized and edged with alkali-felspar, and some iron-ore, in a copious granophyric matrix.*

B. (22274)×20. *Granulitic mass presumably produced by the complete assimilation of gabbro material by acid magma. The rock contains a green strongly pleochroic augite, similar to that encountered in the Camphouse Augite-diorite (p.* 153, Fig. 17).

Granulites and Xenolithic Masses.—Throughout the Hypersthene-gabbro, but perhaps more frequently near the margins, we encounter sheet-like strips of dark-grey fine-textured rocks that are now more or less reduced to the condition of granulites by the metamorphic action of the intruded mass in which they lie. These granulitic strips are sharply marked off from the rock that envelops them, and in the majority of cases it is evident that they are remnants of rock-masses that were solid before the intrusion of the gabbro as a whole. It is equally clear that not all of them had the same origin, although they are generally similar in their mode of occurrence. Many are of gabbro, but others may be referred to early cone-sheets or even basalt lavas.

As a group they are similar in all respects to the granulitic masses that occur within the gabbros of Skye,[1] and in the marginal portion of the Eucrite of Ben Buie in Mull,[2] which in the latter instance were regarded as metamorphosed remnants of some early basic intrusion or intrusions.

In the case of Ardnamurchan, the evidence supplied by the Hypersthene-gabbro and by other units of the plutonic complex tends to show that very frequently the major intrusions had early-consolidated margins against the country rock which became involved, granulitized, or otherwise modified by the continued uprise of magma from below. Sometimes the effects were purely thermal, but at other times differentiation, progressing concurrently with intrusion, produced a magma that was capable of interaction with the already solid margins, and thus special mineralogical readjustments were effected.

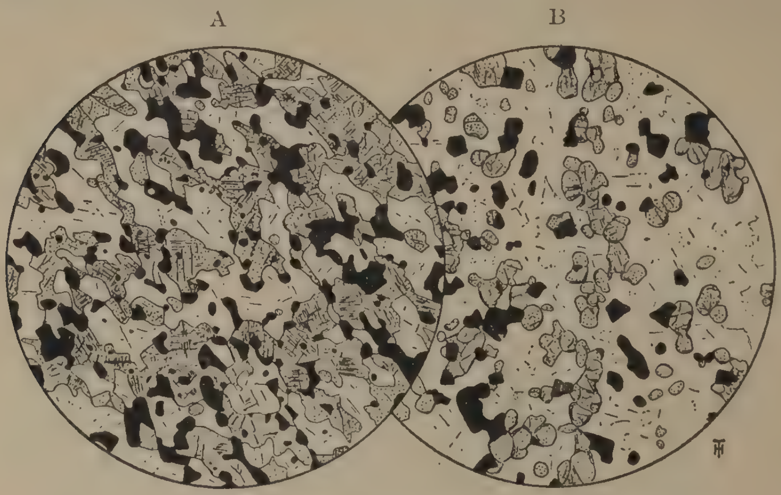

FIG. 31.—*Granulitic Masses associated with Basic Ring-dykes.*

A. (22658) ×20. *Granulitic gabbro, at margin of Great Eucrite south-west of Meall nan Con. A completely recrystallized rock composed of augite, clear plagioclase, and abundant iron-ore. All the constituents tend to have a granulitic development.*

B. (23620) ×20. *Granulitic gabbro of allivalitic composition, enclosed by Hypersthene-gabbro. It is composed of granulitic olivine, basic plagioclase felspar, and iron-ore. The rock has been completely recrystallized and has developed a faint banding.*

Dealing first with those granulites which from their composition and structure must have been solid igneous rocks prior to the intrusion of the main gabbro-mass, we encounter a variety of types that cover a moderately wide range in composition. This range of composition, however, is really no more marked than, and is of a similar order to, that exhibited by the main mass of the intrusion. Usually the granulites are at least as basic as the gabbro that envelops them, and quite commonly they are more so. There appear to us to be good reasons for regarding most of these inclusions as cognate to the main intrusion and not as of accidental type. There are, however, xenoliths of obviously unrelated character, among which one interesting type carries sapphire.

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[1] A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, pp. 115, 116.

[2] H. H. Thomas *in* 'Tertiary Mull Memoir,' 1924, pp. 252, 253.

The fine-textured gabbro of the western coast, to the south of the Lighthouse, is replete with granulitic masses, and it is from here that many of our best examples have been gathered.

The degree to which granulitization has proceeded in these masses is somewhat variable, but it appears to bear little or no relation to the position that the included mass occupies with respect to the margins of the intrusion. If, however, any generalization may be suggested it is that those masses which occur well within the intrusion, in what may be termed its outer central portion, are more finely textured and more completely recrystallized than are those which are situated nearer to the outer margin.

The gabbro in the immediate proximity of such masses shows no signs of chilling, and the junction of the two rocks, although clearly defined, is of the welded type. It is probable, however, in fact almost certain, that the greater part of the granulitization was effected in many instances before the included mass reached its present position, and possibly before it was stripped from the solid wall of which it originally formed a part. This view is strengthened by the fact that many of the masses had been shattered and otherwise broken up before a granulitic structure was impressed upon them. Specimens of such masses, collected not far within the outer edge of the gabbro, are of a moderately coarse-textured hypersthene-bearing rock that has been shattered and then granulitized (22670). It is the crushed portions that have responded most readily to the granulitizing influence, and thus the fractures left by the crushing have been largely healed, but not completely obliterated, by the recrystallization. The original larger felspathic components of the rock have suffered little internal change, but they have been extended by subsequent growths that took place concurrently with the granulitization of the body of the rock. The augite has granulitized into small irregular ophitic and poecilitic patches that enclose granules of felspar, and iron-ore is more generally distributed. Hypersthene builds ophitic masses which, in some instances, are products of recrystallization, but in others probably remnants of the original hypersthene of the gabbro. In the crushed and more completely granulitized portions, the rock consists of a mass of water-clear prisms and grains of a moderately basic labradorite, with granules of augite, rhombic pyroxene, and magnetite.

Another strip of granulite (22671) from an adjacent part of the gabbro is of finer texture and has been completely recrystallized. It consists of a mosaic of clear unzoned labradorite through which are scattered small irregular plates of poecilitic augite with diallagic structure, and a few small patches of opaque iron-ore which enclose granules of felspar after the manner of the augite. Other granulitic strips are of the granulitic gabbro type (22668, 22669, 23631, 23632, 22281), but others again (22667, 23620, 23633) are finer-textured rocks with a typically developed fine granulitic structure throughout. In these we meet with some mineralogical as well as structural differences, chiefly due to the respective parts played by olivine and pyroxene, but in a less degree to slight original differences in composition. In some instances, in which olivine is the dominant ferromagnesian constituent (23620), the rocks may with propriety be described as olivine-granulites, for they consist of a granular aggregate of colourless olivine, basic plagioclase, and magnetite (Fig. 31 B). Such rocks are granulitic representatives of the allivalitic varieties of the normal gabbro. In other cases, rocks of almost equally basic character (23633) have olivine replaced by hypersthene, and consist of a fine-textured granular aggregate of highly pleochroic hypersthene, basic plagioclase, and magnetite. A section across the junction of such a granulite with the gabbro shows a sudden change from the fine-textured well-granulitized rock to a normal moderately coarse hypersthene-gabbro that contains large areas of hypersthene and diallagic augite.

Yet another type of fine-grained granulite (22667), which reproduces in some measure the mineralogical characters of the preceding, contains abundant olivine as well as pyroxene, but in this case the pyroxene is a monoclinic variety.

All these types are moderately rich in ferromagnesian constituents and fairly basic plagioclase, and are just such as would arise simply from the granulitization of fine-textured basic portions of the gabbro. The possibility, however, of some of them being recrystallized basalt lavas must not be lost sight of.

The coarser-textured masses that occur as included strips are certainly recrystallized rocks for the most part, and are best designated granulitic gabbros, but even these have a generally less coarse texture than the rock that envelops them. In most of these, hypersthene is well represented, in some cases being a product of recrystallization and in others probably original (23631). Some of the rocks are unusually felspathic (22668) and consist mainly of partly recrystallized labradorite zoned to oligoclase, in fairly large interlocking individuals.

Near the inner margin of the gabbro mass, where some of these granulitic masses come within the influence of the Quartz-dolerite Ring-dyke of Sgùrr nam Meann, they have had further contact alteration and occasional modification by acid juices. In such cases (23634) there has often been a development of biotite or dark-green hornblende as the results of interaction.

Turning now to those masses which we have reason to believe are of accidental xenolithic character, there are certain fine-textured granulites with porphyritic felspar which are in all probability included basalt lavas. Their type of granulitization and their constituent minerals are the same as those of the granulites described above, but their structure is somewhat different. They frequently show a banding (22031), the bands being composed either almost entirely of felspar or of olivine, hypersthene, and magnetite. In the field, the structure of one such rock suggests that the felspathic bands are due to the drawing out and recrystallization of original felspar phenocrysts (pp. 221–2).

Some of the most interesting accidental xenolithic masses, however, are certain fine-textured, dark-grey rocks that occur at the outer margin of the Hypersthene-gabbro, on the northern flank of Glebe Hill, three quarters of a mile north-west of Kilchoan. These xenoliths are individually several feet in extent and are remarkable for containing abundant plates of deep-blue sapphire visible to the naked eye, and which may attain 2 or 3 millimetres in width. They are associated with a compact dark-grey hypersthene-olivine-granulite (27208), very similar in type to those met with as inclusions in certain of the other gabbro masses and forming portions of Meall nan Con Screen (Fig. 31 A, p. 230). This fine-grained granulite is perhaps an early consolidated portion of the Hypersthene-gabbro which has gathered to itself masses of aluminous country rock, and which has been metamorphosed by the later intrusion of the main mass of the gabbro. The sapphire-bearing rock is compact and very fine grained for the most part, but locally exhibits small felspathic areas reminiscent of the anorthite-sapphire-spinel assemblage that was so characteristic a feature of the sapphire-bearing xenoliths of Mull.[1]

The sapphire-bearing xenoliths, where in contact with the hypersthene-granulite, show a narrow reaction zone, about four inches in width, traversed by a banding that is parallel to the outer margin of the included mass. This is evidently a reaction zone between the aluminous rock and the granulite. Microscopically the xenolith is found to be composed, in the main, of a deep sage-green spinellid that is opaque except in the thinnest sections, a water-clear basic plagioclase, and blue to colourless corundum. The rock is non-magnetic and therefore it would appear that the spinellid is entirely an iron-alumina variety allied to the pleonaste-hercynite that occurred in the Mull aluminous xenoliths. The spinel exists as minute octahedra and also as irregular grains that may coalesce into quite large masses. Although mainly concentrated in what appears to be a devitrified glassy matrix, it also occurs indiscriminately scattered through the felspar and corundum, and was thus an early precipitation. Its abundance is responsible for the extremely dark colour and high density of the rock as a whole.

The corundum builds small well-shaped hexagonal basal plates modified by rhombohedra and without any obvious development of prism-faces (Fig. 32 A). The crystals average about 0·5 millimetres in breadth and are usually about four times as broad as they are thick. As is a common feature of sapphire the intensity of blue colour often varies considerably in different parts of the same crystal and in different individuals. Some crystals are deep blue, others feebly or unequally tinted. The deeply-coloured crystals exhibit the usual pleochroism in shades of blue and greenish-blue: ω = sapphire blue; ε = pale greenish-blue to sea-green. Where most abundantly developed, like the spinellid, it has a yellowish crypto-crystalline matrix that suggests a devitrified glass (24490 and 24490 B.). Some areas of the xenoliths are predominantly felspathic, and in these spinel is, generally speaking, more abundant than corundum (24491). The felspar forms a mosaic of much twinned small crystals of approximately anorthite composition, but there has usually been some regrowth of the early-formed individuals with the addition of a less basic species. The basic portions of the crystals are frequently charged with slender needles of mullite[1] (24490) after the manner of the anorthite in the Mull xenoliths. No unaltered cordierite has been detected, but certain micaceous pseudomorphs in the matrix of the sapphire-rich portions of the rock, that is to say in those parts that appear to have experienced actual fusion, suggest its presence.

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[1] H. H. Thomas, 'On Certain Xenolithic Tertiary Minor Intrusions in the Island of Mull,' *Quart. Journ. Geol. Soc.*, vol. lxxviii., 1922, p. 229. *See also* 'Tertiary Mull Memoir,' 1924, pp. 274–279.

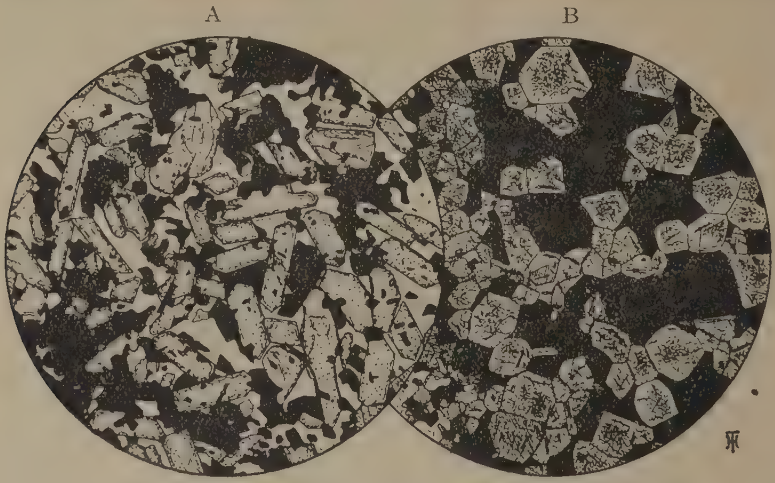

FIG. 32.

A. (24490 B.) × 20. *Sapphire-spinel rock xenolithic in the Hypersthene-gabbro. The section shows well-formed crystals of corundum and an almost opaque spinellid in a chloritic base.*

B. (24440) × 20. *Spinel-magnetite rock occurring as streaks in the Quartz-dolerite of Sgùrr nam Meann. The section shows well-shaped crystals of dark-green spinel containing skeletal growths of magnetite, set in a matrix largely composed of magnetite. Certain bands contain a basic plagioclase felspar of which a little is visible in the lower portion of the section.*

The nature of the original rock that furnished the xenoliths is somewhat obscure, but the high alumina and iron content, especially the former, would render the possibility of its having been igneous exceedingly remote. It is obvious that transfusion from the surrounding gabbro-granulite has been of very limited extent and thus the composition of the xenoliths may be regarded as unchanged. The only rock that appears to have an initial composition likely to yield such a mineral assemblage when metamorphosed is some such highly aluminous and ferruginous deposit as bole, and I would suggest that such was the original nature of the mass. This view is perhaps strengthened by the close proximity of basalt lavas, and by the absence of any highly aluminous deposits from amongst the pre-Tertiary sediments of Ardnamurchan.

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[1] N. L. Bowen, J. W. Greig, and E. G. Zies, 'Mullite, a silicate of alumina,' *Journ. Wash. Acad. Sci.*, vol. xiv., 1924, p. 183.

Contact-Metamorphism of Country Rocks.—The metamorphic effects produced by the intrusion of the Hypersthene-gabbro can be studied to advantage along its southern margin towards Beinn nan Codhan, and north-west of Kilchoan, along the eastern side of the Kilchoan–Achnaha road. Here, a variety of rock-types are involved which include Lower Lias shales and limestone, limestones of Inferior Oolite age, and Tertiary basalt lavas, tuffs, and cone-sheets. The metamorphism is of a fairly high grade, and considering the steep inclination of the intrusive junction, at any rate west of the Kilchoan–Achnaha road, its effects are in evidence over a surprisingly wide zone, a quarter of a mile or more in breadth.

The Lower Lias sediments (Pabba shales) are well exposed on Dubh Chreag, three quarters of a mile east of Beinn nan Codhan. Under the influence of the intruded gabbro they have passed from their usual soft, dark-grey condition into medium-grey finely-crystalline splintery rocks, strikingly different in appearance to their unaltered representatives in other parts of the district (p. 41).

These shales are composed largely of detritus from an old land-surface of schists and gneisses and have given rise to contact-rocks of rather peculiar type. Close to the gabbro-contact they were possibly more chloritic and sericitic than the other members of the series, and are now reduced to the condition of hypersthene-biotite hornfelses (23626, 23629, 21501). Under the microscope, viewed with ordinary light, the most conspicuous constituents are biotite in sponge-like masses, magnetite, and hypersthene in small patches and hypidiomorphic grains. These are set in a colourless base that consists mainly of felspar with what appears to be cordierite. The biotite is intensely pleochroic and of a rich red-brown colour. The hypersthene is a deeply-coloured variety, and even the small granules exhibit an intense pleochroism from bluish-green to pink. It occurs as scattered hypidiomorphic granules for the most part, but may also form moderately large ophitic patches and granular streaks (23629). Apatite occurs as slender needles. The base has almost the appearance of a crystallized melt, and it is certain that the rock narrowly escaped fusion into buchite. It consists of minute stumpy prisms of labradorite-andesine felspar, frequently zoned with oligoclase, in an ultimate base of alkali-felspar with a little quartz. Occasionally a micrographic intergrowth of the last-named minerals can be detected. In addition, the felspathic base includes a number of minute rectangular pinitic pseudomorphs that, in such an association, are most probably after cordierite

(23626, 21501), but no unaltered examples of this mineral have been noted. These biotite-hypersthene-cordierite hornfelses are similar to those met with, and described by Dr. Tilley,[1] in the Comrie region and which he attributes to the metamorphism of chloritic sericitic sediments. In the altered Liassic shales spinel appears to be unrepresented. A fair quantity of an opaque mineral scattered throughout the rock as minute grains is probably magnetite. The absence of spinel may be due to a silica content slightly higher than that of the sediments which have given rise to the hornfelses of Dr. Tilley's Class 4.

More calcareous bands in the Lower Lias (probably the Broadford Beds, p. 41), have been converted into hornfelses that are usually rich in monoclinic pyroxene. One such rock from Dubh Chreag (23627), some hundred yards from the gabbro margin, consists essentially of a monoclinic pyroxene, green hornblende, a basic plagioclase, and large sponge-like crystals of sphene.

The pyroxene is almost colourless in thin section, but locally takes on a pinkish-brown tint reminiscent of hypersthene. Its extinction and other optical properties, however, are those of a monoclinic variety, and it is presumably a diopside of somewhat unusual tint. The hornblende is actinolitic and occurs either in association with the pyroxene or as small isolated individuals. The sphene, which is one of the larger components of the rock and poecilitically encloses felspar, is strongly pleochroic after the usual manner of metamorphic examples of this mineral. In this particular instance garnets are absent, but in other cases, when the original rock was still more calcareous, the hornfelses are garnetiferous, and tremolite is a common constituent. Such a rock (22628), from the same locality as the above, consists of small colourless garnets and small granules of lime-felspar (near anorthite in composition), set in a matrix that consists mainly of tremolite and actinolitic hornblende.

The purer limestones of the Inferior Oolite, which succeed the Lias towards the south and are thus still further removed from the gabbro margin, show the results of fairly intense thermal alteration. They have been marmorized with the formation of various lime silicates. As represented on the coast to the north-west of Sròn Bheag (22440) and half a mile from the gabbro, the rock is a dirty-white to grey, speckled and streaked, fine-grained crystalline limestone of somewhat variable texture. It consists of recrystallized calcite with which are associated small irregularly formed pale-yellow to colourless garnets, and minute elongated crystals of diopside and tremolite.

The Tertiary lavas and cone-sheets that come within the influence of the gabbro have likewise suffered considerable alteration of a type recurring in the lavas and cone-sheets that form portions of screens at various localities within the main plutonic area (p. 313). The actual contact-effects of the gabbro on these rocks, however, can be studied to best advantage in the strip of basalt lavas which occurs to the south-east of Beinn na Seilg, and in the variety of rocks that flank the Kilchoan–Achnaha road, north of the Free Church, on the western slope of Glebe Hill north-west of Kilchoan.

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[1] C. E. Tilley, 'Contact-Metamorphism in the Comrie Area of the Perthshire Highlands,' *Quart. Journ. Geol. Soc.*, vol. lxxx., 1924, p. 22.

In this section the most noticeable changes in the hand-specimen are an increased toughness of the rocks as the gabbro is approached and the development of a more obvious crystalline texture. In addition, small brown scales and patches of finely-divided biotite make their appearance and represent a change in the body of the rock, or the metamorphosis of chlorite-filled vesicles in the case of the lavas. Generally speaking, the texture of the metamorphosed rocks becomes coarser and recrystallization more marked as the gabbro-contact is approached.

On the Achnaha road, the basalt lavas are of both porphyritic and non-porphyritic types, and they are usually amygdaloidal. They are now completely granulitized. The original augite has either largely redistributed itself as small granules, or has passed over into granular rhombic pyroxene. Frequently, regenerated pyroxene may be seen stringing the larger felspars in an irregular manner, developed along cleavage lines (22239–40), or following the course of albitization. All chlorite has been converted into biotite, but some of the mica has reverted to the original mineral as the result of weathering. Biotite has developed in the neighbourhood of iron-ores, and the vesicles are either entirely occupied by this mineral or are lined with biotite, while their central portions are occupied by granular pyroxene (22243). There is usually a well-marked albitization of the larger felspars that have escaped recrystallization, and this applies more particularly to the porphyritic lavas.

The cone-sheets, as might be expected, exhibit changes of a similar order to those presented by the metamorphosed lavas, and which may best be described as granulitization. In spite, however, of considerable recrystallization the characteristic structure of the original rock is seldom wholly destroyed, and the manner of occurrence in the field, with their definite fine-textured edges (22238), leaves no doubt as to their original nature. The cone-sheets and basalt lavas near the gabbro margin, as also the included granulitic masses on the other side of the boundary (p. 231), frequently show traces of a more or less intense crushing that must be regarded as an early effect of the gabbro intrusion. The crushing was usually followed by contact metamorphism that in a measure repaired the damage by partial recrystallization, more particularly in those portions of the rock which had been more or less completely comminuted (22246–7). The usual changes attributable to contact-action in these rocks are a general development of biotite from chlorite, a granulitic recrystallization of augite, local recrystallization of felspar with a somewhat general albitization of the larger individuals, and a migration and general distribution of recrystallized iron-ore.

H.H.T.

(*b*) OLD GABBRO OF LOCHAN AN AODAINN

Of this intrusion, remnants only are left, which are cut by all the adjacent ring-dykes. Towards an inner original margin against agglomerate and basalt lavas, the rock becomes finer grained, and resembles a quartz-dolerite (21570). There is no doubt as to its intrusive relation to these older rocks, for an intrusive tongue of gabbro extends into the agglomerate east of the N.-S. stream that runs northwards towards Aodann.

The Old Gabbro must have been intruded in relation to the Earlier Ring-dyke Centre (2). Sufficient of the original inner wall is preserved to demonstrate a curvature about Aodann. On its outer side, however, it is in contact with at least three separate later intrusions. Whether this outer edge is near to the original outer margin or not there are no means of knowing. At any rate, it marks a fracture, or fractures, the result of which is a curve conforming to the inner margin and to the Aodann Centre (2). On a hillside north-east of Garbh-dhail, the junction of the Quartz-gabbro (c) with the Old Gabbro is apparently steep. For this reason, and also on account of the ring-dyke pattern of the Old Gabbro, it seems certain that the Old Gabbro extends in depth like a ring-dyke, and is not merely capping the Quartz-gabbros (c) and (d) with which it is mainly in contact.

The Old Gabbro is certainly of early date. Though it is only known to be traversed by a single porphyritic cone-sheet, it is definitely proved earlier than the Inner Cone-sheets generally, since it is intruded by the Grigadale Granophyre (c′) and Garbh-dhail Quartz-gabbro (c), both of which are profusely cut by the sheets. Its antiquity might also be inferred from its highly altered condition. In the hand-specimen it is a similar rock to the Hypersthene-gabbro (a), being moderately coarse grained, and pyroxene-rich. It differs however in not containing hypersthene, so far as is known, and also in the cloudy appearance of its felspars under the microscope. This cloudiness has been also noticed by Dr. Thomas in other gabbros that have been contact altered, but in no other mass is it developed to such an extent, as a general characteristic of the rock. It is to be correlated with the remarkable black or bluish-black hue of the gabbro, characteristic of weathered surfaces in the field.

In the vicinity of Lochan an Aodainn (or Lily Loch), the normal coarse-grained augite-rich type is most usually met with, but frequently allivalitic olivine-rich patches occur, in which the olivine weathers with a reddish-brown colour. Sometimes the rock is dappled over with coarsely crystalline acid spots. Though these seem to be original, because they appear to be completely isolated in the dark gabbro, it is possible that acid magma has inserted itself and hybridized with the Old Gabbro in a spotty manner (*see* p. 240). Epidote is of frequent occurrence, more especially in the acid spots. In the coarse type, large ophitic augite-plates are often seen, which glint in mirror fashion when viewed from certain angles. A coarser type than usual, with blade-shaped pyroxenes, occurs on a rocky bluff fringed with trees on the south-west side of the Allt Garbh-dhalach.

A fine-grained type is also met with, smooth-weathering and therefore easy to distinguish from the coarse type which has highly roughened, knobby surfaces. Sometimes these two types may be seen in sharp contact. Both, however, seem equally metamorphosed, and they are too closely associated to be considered other than parts of one intrusive mass.

It is possible that the fine-grained portions above referred to are of xenolithic origin. Only one specimen was collected, which occurs as a sheet-like band. It is suggestive that this rock is granulitized and, according to Dr. Thomas, resembles the non-porphyritic quartz-dolerite type characteristic of the majority of the Outer Cone-sheets. It shows in its cloudy felspars that it has been altered in the same way as the Old Gabbro itself (24429). J.E.R.

Petrology.—The gabbro of Lochan an Aodainn, as might be expected from its position and relative antiquity, has suffered considerably at the hands of later intrusions by which it is hedged in and intersected. It has had impressed upon it widespread textural and mineralogical changes of both dynamic and thermal character, and in these changes lies its chief petrological interest.

The gabbro in its original condition was a somewhat variable olivine-bearing doleritic type, and many of the variations, which have been described above, are clearly related to original textural and mineralogical features of the mass, and are such as can be paralleled in most of the Tertiary gabbros.

The rock almost invariably shows evidence of crushing, shattering, and granulitization. In its coarser variety (21568) it is an olivine-gabbro in which the pseudomorphs after olivine have been replaced by a fine aggregate of biotite, magnetite, and granular pyroxene. The felspars are schillerized and turbid, as a result of reheating, and granulitization has taken place along lines of crush and along cleavage planes in the felspars. In some varieties olivine had a definitely porphyritic habit (22283), but in other instances the rock appears to have been olivine-free. In the latter cases (21516, 21277) the texture assumed is that of a moderately coarse dolerite, composed of ophitic augite, labradorite, and iron-ore. The felspars are turbid and the augite exhibits local schillerization, both the results of subsequent thermal alteration. The augites and felspars are traversed by narrow zones of crush which have been granulitized, and it would appear that the granulitization followed immediately after, or was attendant upon, the crushing. Although the production of hypersthene is a common result of the process of granulitization (22283), especially in areas that were once occupied by olivine (21278), hypersthene does not appear to have been an original constituent of the gabbro, and thus the mass seems to be essentially different from the Hypersthene-gabbro (a) described above (p. 223). In one instance only has hypersthene that may be an original constituent been encountered (21252). In this case hypersthene occupies areas comparable in size to those of olivine.

but the mass has been crushed, and contact altered, and there has been a considerable amount of recrystallization.

The olivine of this gabbro is usually pseudomorphed, and the pseudomorphs, originally chloritic, serpentinous, or hornblendic, have passed over as the result of thermal alteration to aggregates of biotite, and monoclinic and rhombic pyroxenes. In some instances where original decomposition was delayed fresh olivine is still met with (22283), but this is the exception.

The original augite has developed schiller structure, and in the more completely granulitized rocks has been replaced by granular pyroxene-aggregates (24426). The amount of shattering to which the mass has been subjected varies from place to place. In some instances there is scarcely a crystal that has not suffered rupture and some displacement (22286). Hand in hand with the shattering and granulitization of the mass goes a segregation and migration of acid material that locally assumes the more or less definite character of an augite-granophyre (22331). Such acid rocks generally contain a good deal of basic plagioclase and old granulitized augites, which probably belong to the surrounding gabbro, while a certain amount of pyroxene appears to have separated out in the form of enstatite-augite. More generally the gabbro is locally impregnated with acid matter after the manner of the quartz-gabbros, and it is most difficult to conclude whether we should regard this acid material as representing an acid residuum of the gabbro magma or as a separate and subsequent injection.

There has been a general acidification of the gabbro (22332), which takes the form of albitization and deschillerization of the felspars (21561), the formation of rhombic pyroxene, separation of biotite, and the formation of definite lakes of micrographic quartz and orthoclase. Granophyre veins are also frequently met with (21571, 22313).

This migration of acid material through the body of the gabbro in all cases follows the shattering that the mass has undergone, but it is quite possible that it is contemporaneous with at any rate one stage of the granulitization.

Occasionally within the gabbro are encountered basic masses that from microscopic examination suggest cone-sheet material. Such a quartz-dolerite (22461), with, of course, all the original augite converted into granular pyroxenic aggregates, was collected from the gabbro near its western extremity.

The basalt lavas and agglomerates that form the inner margin of the gabbro to the south of Lochan an Aodainn are in a severely metamorphosed condition. Not only have they suffered at the hands of the gabbro itself, but they have come under the same set of metamorphosing conditions as affected the gabbro after its consolidation. The fragments in the agglomerate are similar to those met with in the agglomerates of the vents of Centre 1 and consist of basalt lavas (21813), and trachytic rocks with perthite phenocrysts (21814). Tuffs in a metamorphosed condition are also represented (22310).

The basalt lavas, while retaining their major structures, have passed over to beautiful pyroxene-granulites, in which the development of hypersthene is particularly well marked in the neighbourhood of siliceous strings and patches (22300).

A somewhat rare occurrence in the agglomerates of Lochan an Aodainn is of a quartz-dolerite of Talaidh type (21815) which, like the basalts, has suffered a granulitization of its ferromagnesian constituents; also of a rock which suggests the granulitized chilled edge of a quartz-dolerite of the same type (21500). It would therefore seem probable that cone-sheets were involved in the agglomerates before the intrusion of the Aodainn gabbro (*see* p. 131).

H.H.T.

CHAPTER XVII

TERTIARY RING-DYKES OF CENTRE 2, ARDNAMURCHAN (*continued*)

The intrusions to be described in this chapter are as follows (*see* Index Map, p. 201) :—

(c) Quartz-gabbro of Garbh-dhail.
(c′) Granophyre of Grigadale.
(c″) Older Quartz-gabbro of Beinn Bhuidhe.
(d) Quartz-gabbro of Aodann.

The above intrusions are abundantly cut by the Inner Cone-sheets, excepting the Quartz-gabbro of Aodann which, as already mentioned, lies on the concave side of the belt of country traversed by these sheets (p. 207). Individually, the first three can hardly be said to conform to a ring-pattern, though, regarded collectively, they indicate an arrangement around Centre 2. The inner intrusive margins of the Quartz-gabbro (c) and the Granophyre (c′) against the Old Gabbro (b) certainly conform to Centre 2. Also, the outer margin of the Quartz-gabbro, though in contact with a later ring-dyke, the Beinn nan Ord Eucrite (f), is a fine-grained marginal type of rock north-east and westwards of Beinn na Seilg, and runs parallel to its inner intrusive margin. The ring-fracture into which the Eucrite (f) was intruded would appear to have closely coincided with the outer edge of the Quartz-gabbro.

An interesting feature of the Quartz-gabbro (c) is the development of flinty crush-rock in its outer marginal portion, which was recognized by Mr. Bailey. This is, so far as is known, the first record of flinty crush-rock in British Tertiary igneous rocks.

(c) QUARTZ-GABBRO OF GARBH-DHAIL

Great variations in composition and texture occur throughout this mass. Generally, more basic and also finer-grained varieties are found in the exterior portion, while towards the inner margin more acid quartz-gabbro is prevalent. At several points within the mass quartz-gabbro may be seen to grade into quartz-dolerite with porphyritic felspar, which is found in other quartz-gabbro intrusions to occur as a marginal variety. A sharp, apparently intrusive, contact between different varieties of quartz-gabbro has been noted at one place, as described below. There seems good reason therefore to believe that we are dealing with a complex mass. Everywhere the mass is intruded by the Inner Cone-sheets, so that its components must, at any rate, all belong to approximately the same period.

The fine-grained marginal type along the outer margin is evidently baked. This is attributed mainly to the Eucrite of

Beinn nan Ord, and, in the portion north-east of Beinn na Seilg, to the Quartz-gabbro (A) in addition (*see* pp. 265 and 285). The baked rock, where it forms a ridge along the summit of Beinn nan Ord, is in sharp contact on its inner eastern side with a more acid fine-grained quartz-gabbro. These two rocks were traced side by side along a north-west line for a few hundred yards, but their separation could not be carried farther. The marginal type can be traced eastwards around to the north-east side of Beinn na Seilg, where it comes next to the later Quartz-gabbro (A). In this vicinity, the fine-grained rock, when traced westwards, passes gradually into coarser-grained quartz-gabbro, and so appears here to be a definite marginal facies of a larger mass.

Flow-banding is sometimes seen, and is inclined inwards towards the Aodann Centre (2) at high angles.

Xenoliths are plentiful locally, and sometimes occur as bands of fine-grained basic rock—as in the Hypersthene-gabbro. Examples may be seen west of the N.-S. fault marked by a stream-hollow west of Beinn na Seilg, and 400 yds. south of a patch of marshy alluvium shown on the one-inch Geological Map (Sheet 51).

Acid veins traverse the xenolithic bands just mentioned, as well as the quartz-gabbro generally. They are perhaps most abundant north-west of Beinn na Seilg. That some of them, at least, were derived from the Garbh-dhail Quartz-gabbro itself, during the later stages of its consolidation, is suggested by the fact that such veins are cut by the Inner Cone-sheets. North-east of Beinn na Seilg, where the Garbh-dhail Quartz-gabbro forms a roof to the younger Quartz-gabbro (A), an example of this relation was noted, and under the microscope the cone-sheet concerned (24445) was found to be contact altered. The alteration is ascribed to the adjoining Quartz-gabbro (A). The pre-sheet acid veining cannot therefore be attributed to (A).

The effects of earth-stresses are frequently very evident. For example, in the area south-west of the Grigadale Granophyre, west of the Allt Grigadale, the Quartz-gabbro is cut to pieces with lines of shear, and is much broken up in appearance. Again, on the south-east shoulder of Beinn nan Ord and in the hollow immediately to the east, shear-lines and also bands of black flinty crush-rock are abundant. This linear shearing is of early date, preceding the intrusion of the Inner Cone-sheets. In no other mass in Ardnamurchan have such pronounced effects of earth-stresses been noted. They are even more marked than the shearing found along the course of the Loch Bà Fault in Central Mull.[1]

Age Relations.—The intrusions that are both earlier and later than the Garbh-dhail Quartz-gabbro (c) are tabulated below, together with the kind of evidence on which their relative ages are based.

OLDER INTRUSIONS.	EVIDENCE OF AGE.
Hypersthene-gabbro (a)	(c) marginal type against (a) non-marginal type.
Old Gabbro (b)	(c) chilled against (b).

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[1] W. B. Wright *in* 'Tertiary Mull Memoir,' 1924, pp. 340, 341.

YOUNGER INTRUSIONS.	EVIDENCE OF AGE.
Grigadale Granophyre (c′)	(c′) chilled against (c).
Beinn nan Ord Eucrite (f)	(f) marginal type against baked (c); (c) sheared and cut by minor intrusions (Inner Cone-sheets) next to (f) unsheared and uncut by minor intrusions.
Quartz-gabbro (A)	(c) cut by Inner Cone-sheets, both being baked next to (A) uncut by these cone-sheets.

In the case of the above-mentioned younger intrusions, evidence of age will be dealt with in detail under the headings of these intrusions. Descriptions of contacts between the Garbh-dhail Quartz-gabbro and the older intrusions are given below.

Contact with the Hypersthene-gabbro (a) occurs eastward of Beinn na Seilg. In contrast to its condition on its outer margin, the Hypersthene-gabbro is on this, its inner side, a coarse grained rock. The Quartz-gabbro (c) alongside is, on the other hand, fine in grain, and is profusely cut by acid veins. The best locality for studying the contact is on the north-west side of the rocky summit of Stacan Dubha, north of the twin lochs and east-north-east of the higher, southern, peak of Beinn na Seilg. The evidence stated was considered, during the mapping of the junction, sufficient indication of the relative ages of the two masses, though further investigation might be profitable.

Contacts with the Old Gabbro (b) may be seen at several places. A good instance is situated west of the Allt Garbh-dhalach, north-west of a prominent wooded bluff formed of the Old Gabbro, and just south of a projecting tongue of the Quartz-gabbro shown on the Memoir-map. The Quartz-gabbro can be traced for some distance as a practically continuous outcrop up to its contact with the Old Gabbro, east of where a stream debouches from a small patch of bog. Here, grey-black quartz-gabbro with acid patches grades rapidly into a brown fine-grained quartz-dolerite, which is definitely chilled against the Old Gabbro, a black augite-rich rock. The marginal belt of quartz-dolerite is 3 or 4 yds. in width. It may be mentioned that along the west side of the wooded bluff referred to above, the marginal Quartz-gabbro is a fine-grained, brown-weathering dolerite, with gabbroid portions that appear to be acidified gabbro. The petrological characters of this type of rock will be described in detail in the case of the Aodann Quartz-gabbro (d) (p. 252). J.E.R.

Petrology.—The Quartz-gabbro (c) as exposed at Garbh-dhail (21816) is a fairly fine-grained rock composed mainly of a moderately basic plagioclase felspar and augite, with interstitial micrographic quartz and orthoclase, and accessory magnetite and apatite. The felspar is much zoned and twinned. It is usually edged with a fairly wide zone of oligoclase-albite and a narrow border of orthoclase which is optically continuous with the orthoclase of the micrographic matter. The intergrowth of quartz and orthoclase occasionally forms an outer layer to the felspars and presents definite crystal-boundaries towards the larger quartz-areas. The augite has a tendency towards idiomorphism, a feature which is encouraged by the relatively large quantity of fine-grained interstitial material. It has suffered alteration as the result of general reheating. It has evidently recrystallized with the separation of microscopic magnetite, and the occasional adoption of a microgranular structure, without the destruction of the larger crystal-outlines. Biotite and hornblende are also developed as products of its alteration. The interstices between the larger crystals are filled mainly by a copious fine-textured intergrowth of alkali felspar and quartz, while an excess of the latter mineral has given rise to small patches of quartz without crystal form. The abundance of accessory apatite is a feature common to most of the quartz-gabbros and quartz-dolerites, and stands out in contrast to the general paucity of this mineral in the quartz-free gabbros and eucrites.

Southwards towards Beinn na Seilg (21578, 21560) as well as northwards towards the Grigadale Granophyre (21574), the rock is a fine-grained quartz-gabbro or quartz-dolerite with a somewhat variable texture and composition. The texture is controlled largely by the size of the constituent felspars, and the composition by a variation in the amount of augite, iron-ore, and interstitial micrographic material. Towards its outer boundaries, in the direction of the Beinn nan Ord Eucrite, as has already been pointed out (p. 242), we encounter fine-grained and generally more basic types (21242, 21484, 24431). In these the felspars appear to be richer in lime, and although albitized to some extent are less markedly zonal than those of the more acid varieties of the gabbro. At the same time, the quantity of granophyric matter and free quartz is reduced to a minimum. The rocks thus exhibit more normal gabbroic and doleritic characters. Less frequently, as to the north of Beinn na Seilg (21515), the rock passes into an olivine-gabbro of medium texture, which contains fresh olivine with subordinate hypersthene, a moderately basic labradorite felspar and ophitic augite, with practically no accessories.

Included within the Quartz-gabbro of Garbh-dhail are masses of definitely earlier intrusions which have been entirely granulitized in the process of reheating to which they have been subjected. They are mainly fine-textured compact rocks that in some instances show traces of an original porphyritic structure (24433).

These compact granulites (21579, 22680) consist of an aggregate of olivine, augite, plagioclase felspar (labradorite to oligoclase), and, occasionally, a little quartz. Original olivine has frequently reacted with the felspar and produced a reaction zone of augite between the minerals, and a separation of magnetite (24434). There is little doubt that these rocks were originally either dolerites or fine-grained gabbros.

An additional metamorphic change in these rocks, due presumably to intrusions later than the Garbh-dhail Quartz-gabbro, is noticeable in the production of secondary biotite (22680) in the areas occupied by decomposed olivine and its associated magnetite separations.

The Garbh-dhail gabbro-mass is remarkable for the intense shattering that has locally affected it, more particularly at and near its outer margin towards Beinn nan Ord. In all cases that have come under observation (p. 243), cases that are clearly indicated by special features in the field, the disruption that the rock has suffered is truly remarkable (24447, 24405). This disruption is at any rate in part due to earth-movement, for bands of flinty-crush are encountered (24407, 24408), but explosive action also may have been operative. The felspars of such rocks are mostly comminuted, and thus we meet with only a few quite small patches of fine-grained gabbro which have escaped destruction, and which are set in a thoroughly cataclastic matrix. These shattered rocks, as already stated, are mainly close to the Beinn nan Ord Eucrite. The latter mass has also been shattered throughout the greater part of its length, but in this case the shattering is attributed to explosion rather than to earth-movement, of later date than the disruption of the Garbh-dhail intrusion (p. 267). A similar metamorphosing and healing influence, however, has been at work in each case, for the shattered rocks both in the Garbh-dhail Quartz-gabbro and Beinn nan Ord Eucrite have been more or less completely granulitized. In the case of the Quartz-gabbro, the Eucrite is, partly at least, the cause of the granulitization (p. 265). As pointed out in the case of the shattered granulites that occur in the Hypersthene-gabbro (a) (p. 231), the finer cataclastic material has yielded most readily to the metamorphosing influences, and the final structures and mineral assemblages are of a similar kind (24432, 24448). There is evidence that the Quartz-gabbro (c) was completely shattered before certain cone-sheets referable to Centre 2 were intruded, but that granulitization was effected in both (24404).

A series of acid veins (24401) and occasional dyke-like masses (24430) cut the Garbh-dhail Quartz-gabbro but do not penetrate the Beinn nan Ord Eucrite (pp. 267, 281). They thus presumably belong, at least in part, to the gabbro itself, which, as already discussed, may be of multiple nature (p. 242). These acid veins are fine-grained, dark, white-weathering rocks that consist of a mass of quartzo-felspathic devitrified material containing a few small phenocrysts of andesine-oligoclase felspar. H.H.T.

(c′) GRANOPHYRE OF GRIGADALE

This mass occupies a peaty hollow traversed by the Allt Garbh-dhalach east of Loch Grigadale (Fig. 37). In composition, it is very uniformly a rather fine-grained granophyre of basic type. A well-exposed junction against the Old Gabbro (b) may be seen along a scarp bounding to the east the flat peat-covered area underlain by the granophyre, 250 yds. south of the track-road leading from Achosnich to Grigadale farm. The Granophyre is chilled to a felsite at the contact.

A contact with the Quartz-gabbro (c) is seen just east of the Allt Grigadale. Under the microscope, the Granophyre is found to be chilled against the Quartz-gabbro, which is shattered (24429).

Another junction with (c) occurs at the south-east corner of the Granophyre outcrop, 130 yds. south-west of the Allt Garbh-dhalach. Only about 2 feet of the junction are on view on a flat rock-surface. The Quartz-gabbro grades rapidly into a marginal facies, a fine-grained rock with porphyritic felspar, from which veins are intruded into a band of fine-grained basic rock. This band is in contact on its other side, along a clean-cut line, with the Granophyre, which is vertically jointed at right angles to the junction. This contact does not supply any good evidence of the age-relationship of (c) and (c′), though microscopic examination of the rocks concerned might be profitable.

A second, smaller mass of granophyre surrounded by the Garbh-dhail Quartz-gabbro (c) has been mapped on the north-east side of Beinn nan Ord, south of the Grigadale mass (*see* Fig. 37). Owing to poorness of exposure, no contacts with the Quartz-gabbro could be located.

The Inner Cone-sheets that so plentifully cut the Granophyre may be briefly referred to. They are more especially well seen in the western half of the intrusion. All contain abundant porphyritic felspars, have well-chilled margins, and are steeply inclined at about 70 degrees. One individual noted contains numerous basic xenoliths probably of cognate origin, and was traced for some distance on either side of the Allt Garbh-dhalach, about 300 yds. eastward of where this stream enters Loch Grigadale. J.E.R.

Petrology (Anal. III ; Table III, p. 84).—The Grigadale Granophyre as represented by the analysed specimen (22820), which is typical of the mass, is a fine-grained, medium-grey rock speckled with a black ferromagnesian constituent. A few felspars with bright cleavage faces of a millimetre or so in cross section are noticeable on freshly fractured surfaces, but otherwise the rock is very uniform in grain. A comparison of the analysis with those of the Tertiary granophyres of Mull and Skye shows that in general it is slightly less siliceous and richer in the albite end of the plagioclases than is usual, but the departure from the average type is, in reality, slight.

Microscopically (Fig. 33 A), the rock consists of crystals of a medium plagioclase, zoned to albite and edged with orthoclase, which are packed fairly closely together in a fine-textured micrographic matrix of quartz and alkali-felspar. The felspar crystals range up to a millimetre in greatest dimension, and their alkali-felspar edges, owing to their turbidity, stand in contrast to the soda-lime felspar of their interiors.

Augite occurs sparingly, and with a somewhat sporadic distribution. It exists as partially resorbed crystals, turbid with magnetite, and it never appears to be in harmony with its surroundings. It would seem that the whole granophyre is basified to some extent, some parts much more so than others, by contamination with gabbro material. The analysed rock represents the least contaminated portion of the mass, but the resorption of basic material would quite well account for the slight departure of the composition from that of an average uncontaminated Tertiary granophyre. In other parts of the mass, evidence for basification is much more pronounced and conclusive. Here, the plagioclase crystals increase in size, and the proportion of magnetite-charged pyroxenic patches becomes much greater (21575). Although not much darker in general tint, the rock in this form has a more blotchy aspect. In extreme cases, the rock contains so much basic matter that it may almost be described as an acidified gabbro (21582). The basic clots consist of magnetite-charged pyroxenes which have suffered some resorption, granulitization, and recrystallization—the last tending to produce an acicular habit. As a whole, the rock presents a more gabbroic than granophyric appearance; it has a relatively coarsely crystalline texture due to the size and frequency of the pyroxene crystals, but on a weathered surface the granophyric matter shows as a pure-white network that involves the darker constituents.

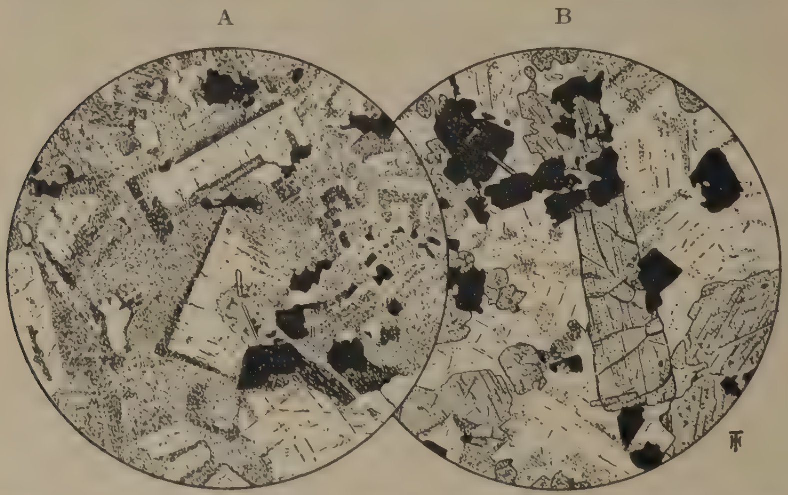

FIG. 33.—*Granophyre of Grigadale and Quartz-dolerite of Sgùrr nam Meann.*

A. (22820) × 20. *Grigadale Granophyre. Crystals of plagioclase edged with turbid alkali-felspar, partially resorbed augites of gabbro origin, and occasional patches of iron-ore, in a granophyric matrix of alkali-felspar and quartz.*

B. (22400) × 20. *Quartz-dolerite of Sgùrr nam Meann. The section shows a large crystal of hypersthene, with partially recrystallized augite and iron-ore, in a matrix of plagioclase felspar that has been invaded by acid material and locally albitized.*

The Grigadale Granophyre, as stated above, is in contact with, and is chilled against, the Old Gabbro (b) (p. 246). The microscope demonstrates the fact that the gabbro is shattered at the junction and that there has been some absorption of gabbro-material by the acid rock (22282).

The junction of the granophyre with the quartz-gabbro to the west (p. 246) exhibits a similar state of affairs. The gabbro has been shattered and locally acidified, while the granophyre at the contact exhibits an accompanying basification (24429).

That the granophyre mass has been thermally affected by subsequent intrusions is suggested by the local development of secondary biotite, slight granulitization, and other metamorphic changes (24395). H.H.T.

(c″) OLDER QUARTZ-GABBRO OF BEINN BHUIDHE

This rock-mass forms the rugged, southern side of Beinn Bhuidhe. In being earlier than the Inner Cone-sheets it differs from the Younger Quartz-gabbro (h) in contact, of which the remainder of Beinn Bhuidhe is composed. In rock-type it differs from the still older Quartz-gabbro (c), being everywhere a grey-black medium-grained rock with light-coloured streaks and patches of more acid character. The latter represent a granophyric mesostasis that is particularly well defined from the gabbroid portions. It bears a strong resemblance to certain varieties of the Old Gabbro (b) which is locally spotted with acid material, and it was indeed at one time taken to be an outlying portion of the Old Gabbro.[1] But, since it presents a very fine-textured marginal facies against the Grigadale Granophyre (c′), and since this Granophyre clearly cuts the Old Gabbro, an age-difference seems apparent.

The locality where the marginal facies against the Granophyre is seen lies south of the Achosnich–Grigadale track-road, 600 yds. south-east of Grigadale farm, and just east of a stone wall, shown on Fig. 37. The black Quartz-gabbro (c″), as it is traced towards the Granophyre, becomes increasingly finer grained and lighter in tint, though still retaining its characteristic dull black hue. Actual contact with the Granophyre could not be established, and the possibility of the one rock grading into the other was at first considered, but closer scrutiny, aided by microscopic examination has made a break apparent between the marginal type, a fine-grained acid quartz-gabbro (24394), and the adjacent granophyre (24395).

Alongside the track-road leading to Grigadale farm, in the west half of the Quartz-gabbro, the latter is traversed by numerous Inner Cone-sheets inclined at angles of 65 to 70 degrees. J.E.R.

Petrology.—Petrographically speaking, this intrusion, which is of somewhat fine texture and dark grey in colour, is a gabbro in all stages of acidification. An acid magma, or partial magma, permeates microscopically the whole mass, but it is also collected into definite areas and strings visible to the unaided eye.

In its more basic varieties (22374), the gabbro is a moderately coarse rock with constituents that range up to several millimetres. It is composed of zoned labradorite felspar, schillered and somewhat corroded subophitic augite, rather copious iron-ore, and a coarse interstitial matrix of alkali-felspar and quartz in micrographic intergrowth. Where in contact with the matrix, the plagioclase is edged with alkali-felspar that is continuous with the orthoclase of the micrographic intergrowth, and in the case of the augite there are evident signs of resorption. South-east of the summit of Beinn Bhuidhe (21555), near to where the mass ends against the Later Quartz-gabbro of Beinn Bhuidhe, the rock shows an increased amount of interstitial felsitic matter and a more marked albitization of the basic felspars. These felspars also exhibit corroded and regrown boundaries against the matrix and are turbid with schiller inclusions. Augite has practically disappeared except where protected from the acid mesostasis by a shield of basic plagioclase. In some cases reaction between the migrating acid matter and the basic constituents of the gabbro has resulted in the formation of biotite in moderately large flakes in a quartzo-felspathic matrix (21279). In such rocks there is some indication of an early shattering of the mass, and albitization of the original felspars is a prominent feature.

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[1] 'Summary of Progress' for 1922, *Mem. Geol. Surv.*, 1923, Fig. 6, p. 99

Towards the Grigadale Granophyre (c′) there is a marginal change in the gabbro (p. 249). A number of specimens taken along a north and south line across the junction, to the east of Loch Grigadale, and representing a horizontal distance of about 150 yds., present the following features. About 100 yds. from the presumed junction the rock (24412) has a moderately coarse doleritic texture and medium to dark-grey colour. It consists of elongated crystals of zoned labradorite-andesine felspar, which are schillerized and bordered by a turbid fringe of alkali-felspar. Enmeshed by these are abundant patches of partially resorbed augite with magnetite, and a copious matrix of alkali-felspar and quartz in fine micrographic intergrowth. Sometimes the micropegmatite assumes the crystal boundaries of orthoclase.

Nearer to the granophyre the rock (24413) keeps the same texture, but is somewhat lighter in tint and more blotchy in appearance, while there seems to be a tendency towards an acicular crystallization of some of its constituents. The microscope shows that the felspars have taken on an idiomorphic habit, chiefly by regrowth and the addition of wide alkaline borders. This idiomorphic growth has to a great extent been permitted by reason of a greatly increased amount of acid mesostasis. The acid matrix is more definitely and more coarsely granophyric, and the proportion of obvious quartz is considerably greater. Remnants of partially resorbed augite are still abundant and sufficient to account for the relatively dark colour of the rock as a whole.

Still closer (24394), the general tint is even paler than before, but continues considerably darker than the pale-grey speckled granophyre (24395) of the Grigadale mass. There is very little change, here, in the microscopic structure except perhaps the more scattered character of the partially resorbed augite, and the segregation of free quartz into well-defined areas, in addition to its dissemination as an intergrowth with alkali-felspar.

Passing to within the Grigadale mass itself (24395), we find a granophyre that is intensely basified with gabbro material. The type of crystallization and the order of contamination are certainly similar in both rock-masses, and on these considerations alone it is impossible to decide which is the earlier intrusion. It does not follow, of course, because the granophyre is basified (p. 247), that it absorbed its basic material from the particular gabbro now in contact with it, and the converse argument applies to the acidified gabbro. The field evidence, however, as set out above, seems conclusively in favour of the gabbro being the later injection. H.H.T.

(d) QUARTZ-GABBRO OF AODANN

The position of this mass almost entirely within the belt of Inner Cone-sheets has already been referred to (p. 242). Only one porphyritic cone-sheet has been recorded as cutting it, at a point close to its boundary with the basalt lavas and agglomerates, 350 yds. south-west of Lochan an Aodainn. No contact between the intrusion and the Later Quartz-gabbro of Beinn Bhuidhe (h), which is later than the Inner Cone-sheets, has been located. Where the two masses probably join, in the vicinity of Achosnich, rock-exposure is poor across grass-covered fields.

The Quartz-gabbro (d) varies from place to place in texture, and also in the amount of the acid mesostasis. A fine-grained type, usually with porphyritic felspar, forms a capping to a hill between Aodann and Lochan an Aodainn. It weathers with smooth pinkish-hued surfaces, and has the appearance of being slightly baked. Downhill, a normal-textured and less durable quartz-gabbro is found, and on the north and south slopes the change in type is abrupt, though to the west there appears to be a gradual passage. On the other hand, at an apparent contact on the north side between the two varieties, the fine-grained rock shows distinct signs of baking (24428). Further, the two varieties differ in their marginal behaviour against the Old Gabbro (b), on the south side of the hill, north of Lochan an Aodainn. The upper, fine-grained, rock makes sharply-defined chilled contacts with the Old Gabbro, which is much veined by granophyre in the vicinity; while the lower, coarser, quartz-gabbro becomes hybridized near to contacts with the Old Gabbro, taking on a black hue on account of contained cloudy felspars that are probably derived from the Old Gabbro (24427, 21561). It is likely that there have been here two injections of magma, the first more quickly cooled and now forming a capping to the succeeding main injection. Farther north, the rock around Aodann, and by the roadside leading towards Achosnich, is a medium-grained quartz-gabbro with abundant grains of iron-ore, and with little acid mesostasis. It locally bears felspar phenocrysts.

Perhaps the chief interest of the mass lies in its relation to the Old Gabbro, which has been referred to above. Some of the contacts may be briefly described. At the north end of the Old Gabbro, along the track leading from Achosnich towards Grigadale, quartz-gabbro grades rapidly into quartz-dolerite with porphyritic felspar, which is in sharp contact with the Old Gabbro. The latter is coarse-grained and black in colour, and can be easily distinguished from the dolerite which is brown on weathered surfaces. Farther south, about two thirds of a mile west-south-west of Aodann, non-porphyritic brown-weathering quartz-dolerite, charged with coarse white-weathering acidified-looking gabbro, forms a broad zone extending for a hundred yards or more from the Old Gabbro, which is contact altered (22283). Sometimes the quartz-dolerite makes sharp contact against the coarse acidified gabbro, which thus appears to be xenolithic. More usually, the relation between the two is a merging one. The acidified gabbro will be described in more detail later (*see below*).

South-east of Aodann and south of Lily Loch (Lochan an Aodainn), the Quartz-gabbro close to contacts with the Old Gabbro becomes dull-black in colour, as has been already remarked of it at another point in the vicinity (p. 251). South of Lily Loch, it is especially clear that the Old Gabbro is intruded by the quartz-gabbro magma, which has penetrated along cracks and into angular spaces in the former, and which in these positions has crystallized as a brown-weathering quartz-dolerite. J.E.R.

Petrology.—The normal gabbro (21563), if normal can be applied to so variable a rock, is a moderately fine-grained, dark-grey, speckled quartz-dolerite. It is composed of augite, rhombic pyroxene, zoned labradorite felspar, and magnetite, with a little interstitial alkali-felspar and quartz. The pyroxene occurs in patches and grains comparable in size to that of the felspars, and has a distinct leaning towards idiomorphism. The augite is frequently schillered and of a pale-greenish tint in thin section. The rhombic variety occurs in somewhat irregularly bounded crystals that have the well-marked pleochroism of hypersthene. Where of somewhat coarser texture (22339), the rock might be described as a diallagic moderately coarse gabbro. The coarse areas occur in a xenolithic manner and often present quite sharp boundaries against the finer-grained material. In a section across such a junction (22339), the coarser, xenolithic rock has been swamped by apatite-rich acid magma that has deschillerized the augite with which it comes in contact, albitized the basic plagioclase, and finally crystallized as a copious interstitial micrographic growth of quartz and orthoclase. The fine-grained rock with which it is in contact is of doleritic composition, but has a pronounced granulitic structure. It consists of augite in small rounded grains, moderately abundant magnetite, and a base of fairly acid plagioclase. The felspar, which has a composition approximating to andesine, forms small elongated crystals for the most part, but is also segregated into larger areas without definite form. In this granulitic base occur large crystals of altered plagioclase, as well as of augite, which are of xenocrystal nature and are presumably derived from the coarser gabbroid rock. Occasionally the rock is definitely porphyritic (22335), the porphyritic crystals being labradorite that has been schillerized, albitized, and regrown.

A strip of dark-grey porphyritic rock (21562) separates the Quartz-gabbro (d) from the Old Gabbro (b) north-east of Lochan an Aodainn, and is evidently a portion of some older mass. It is an interesting rock, because in addition to porphyritic labradorite it contains moderately large phenocrysts of augite and olivine. It has been modified to some extent by the metamorphic action of the intrusions with which it is in contact. Felspars have been schillerized, albitized, and regrown ; olivine, which is partly fresh, is surrounded by a reaction zone of rhombic pyroxene and biotite, while the matrix now consists of a subgranulitic mass of augite, hypersthene, and magnetite with irregularly formed laths of plagioclase (labradorite to oligoclase).

In nearly all these gabbro masses the chief interest lies in the nature of their contacts with adjacent rock-bodies, and much material has been collected and studied with the object of determining their mutual relations and their marginal characteristics. In the case of the gabbro under discussion, specimens have been chiefly collected adjacent to the Great Eucrite (E), and at its contact with the Felsite (j) south of Aodann.

At and near the junction with the Great Eucrite, to the east and north-east of Aodann, the gabbro (d) is fine textured and is perhaps more basic in composition than elsewhere, although quartz is present as an ultimate product of consolidation. Hypersthene and augite, the latter frequently ophitic and diallagic, are the dominant ferromagnesian constituents (22334, 22327), but olivine is occasionally encountered (22323). A still finer-textured rock from this neighbourhood, close to the Old Gabbro (b), is of similar composition. It contains moderately abundant rhombic pyroxene (24428). Most of these rocks show effects of contact metamorphism that must be attributed to the intrusion of the Great Eucrite of Centre 3. Such effects are variously the schillerization of the older felspars, albitization, deschillerization of diallagic augite, and granulitization of the matrix.

At its junction with the Felsite (j), situated some 500 yds. to the south of Aodann, the rock is fine grained and somewhat porphyritic, containing small porphyritic felspars, some half a centimetre in length. It is a dark-grey quartz-dolerite that approaches the Talaidh type in general characters (22338), and shows occasionally a tendency towards a variolitic microstructure. Quite close to the felsite, the rock has been completely granulitized (22337). It consists of a plexus of lath-shaped labradorite-oligoclase felspars with ragged regrown edges, between which lie strings and small granules of greenish augite and strongly pleochroic hypersthene associated with magnetite. The porphyritic labradorite felspars are schillered and albitized, and include abundant granules of pyroxene. Also, large areas are occupied by a secondary brown hornblende that exhibits a poecilitic structure. The intensely metamorphosed condition of the rock in this instance is probably due to the combined action of the Felsite and subsequent later neighbouring intrusions. Farther to the east, against the Old Gabbro (b) and the screen of basalt lava and agglomerate, the rock is of the coarser-grained type (24410, 22312), similar to that which bounds the Great Eucrite to the north, but is variable in the amount of acid mesostasis it contains.

A specimen (21567) collected close to the Old Gabbro is a granophyre-gabbro hybrid, showing gabbro material undergoing resorption by acid magma that has solidified as a graphic intergrowth of alkali-felspar and quartz.

The gabbro east of Aodann encloses certain strips and patches of fine-textured dark rock that are xenolithic in character and certainly represent remnants of some older mass of quartz-dolerite composition. They are usually completely granulitized, with granulitic augite and subordinate rhombic pyroxene (22328). Their structure is similar to that of certain cone-sheets of which it is quite possible they are representative.

From what has been set out above it is clear that this mass, although behaving as a unit, is very variable in texture and composition, and it is more than probable both on field and petrographical evidence that it is of a multiple nature. In places the mass is clearly divisible, there being sharp contacts between coarse and fine-grained types (p. 251).

A somewhat remarkable rock (22329) occurs at one of these contacts about 250 yds. east of Aodann. It is a finely crystalline dark-grey rock banded with coarser and lighter-coloured material. The fine portion may be described as an olivine-granulite consisting of small granules of fresh olivine which poecilitically enclose little rounded cystals of basic plagioclase, an occasional poecilomorphous augite, scattered well-formed magnetites, and a mosaic matrix of labradorite. The coarse bands contain abundant fresh olivine, ophitic schillered augite, large plates of hypersthene, and bytownite to labradorite felspar, the whole with a gabbroid texture. The origin of this rock is obscure, as it is much more basic than any parts of the gabbro. It is possible that it represents a modified mass of a still earlier and more basic rock. H.H.T.

CHAPTER XVIII

TERTIARY RING-DYKES OF CENTRE 2, ARDNAMURCHAN—(*continued*)

THE earlier ring-dykes that remain to be described are as follows (*see* Index Map, p. 201) :—

(e) Quartz-dolerite of Sgùrr nam Meann, veined by granophyre.
(f) Eucrite of Beinn nan Ord.
(g) and (g′) Quartz-gabbros of Loch Caorach and Beinn na Seilg.
(h) Younger Quartz-gabbro of Beinn Bhuidhe.
(i) Fluxion Gabbro of Portuairk.
(j) Felsite, South of Aodann.

All the above intrusions are later than the Inner Cone-sheets, excepting the Quartz-dolerite (e). This intrusion and the ring dykes (f) and (g) keep together as a group throughout the greater part of their course, and it is convenient to describe them consecutively in the same chapter. Their slightly curving form seems sufficiently to establish their connexion with the Aodann Centre (2 of Pl. V), though another explanation of the conformation of the Eucrite (f) might possibly be entertained. This intrusion might be regarded as an outer arm of the Great Eucrite of the Later Complex, which had inserted itself between certain of the Earlier Ring-dykes, and so come to conform to the Earlier Centre. The matter becomes a question of the age relationship of these two eucrite masses. This cannot be directly determined, since the two are nowhere seen in contact, their nearest outcrops being separated by Sanna Bay. Farther south, however, there is evidence of an age difference between them, since the Beinn nan Ord Eucrite (f) is clearly intruded by the Quartz-gabbro (A) on the north-east side of Beinn na Seilg, while there is every reason for regarding the Great Eucrite as later than this Quartz-gabbro.

The relations of the Younger Quartz-gabbro (h) and Fluxion Gabbro (i) to one another and to contiguous masses proved difficult to determine. Whether, indeed, they belong to the Earlier or Later Complex could not be decided in the field, but they seem more conveniently to be classed with the former. On the other hand, it is possible that the Younger Quartz-gabbro is connected underground with the Quartz-gabbro (A) of Centre 3, which disappears under roof to the north of Beinn na Seilg (p. 285). Such a continuation would, perhaps, explain the contact alteration of certain intervening surface rocks, *e.g.* the Felsite (j) (p. 270), which cannot be ascribed to any visible intrusion. Again, the position of the Fluxion Gabbro (i) at the outer margin of the Great Eucrite (E) seems to suggest its correlation with the Fluxion Gabbro (B).

Under the heading of the Felsite (j), a number of other small intrusions of similar felsite which are found within the area of the Earlier Complex will also be described.

(e) QUARTZ-DOLERITE OF SGÙRR NAM MEANN, VEINED BY GRANOPHYRE

Along the greater part of its course, this ring-dyke, together with the Quartz-gabbro (g) immediately inside it, occupies a belt of low ground between the more durable Hypersthene-gabbro (a) and the Eucrite (f). Near its eastern termination, the Quartz-dolerite, south of the southern peak of Beinn na Seilg, traverses the Hypersthene-gabbro, and appears to be fingering out. To the north, it forms the steep-sided hill of Sgùrr nam Meann, which, in contrast to the scenic relations farther south, is flanked to the east by a hollow along which the Beinn nan Ord Eucrite extends. Its harder nature in this vicinity is the result of baking, though the contact alteration seems only attributable to the two intrusions that accompany it here and elsewhere on its inner side—the Quartz-gabbro of Loch Caorach (g) and the Eucrite of Beinn nan Ord (f).

The separation of the Quartz-dolerite in the field from the Quartz-gabbro (*g*) is in some places a difficult matter, but north and south of Sgùrr nam Meann, the writer found that contacts could be established, and search at other places where rock-exposures are sufficiently continuous has corroborated the evidence there noted. It should be emphasized that a very careful examination is necessary to locate these contacts, and that the impression is given at first sight that one rock grades into the other. This, indeed, was the first opinion held. Apart from the direct evidence of the distinctness of the two masses (p. 271), this view in itself presents an element of improbability. For we should then have a single, elongate intrusion with an outer half composed of quartz-dolerite, and an inner half of quartz-gabbro, the former rock frequently containing porphyritic felspar and evidently quickly cooled, the latter coarse in texture except where passing into a quartz-dolerite at its actual contact with the Eucrite of Beinn nan Ord inside it.

The type of rock composing this ring-dyke is a remarkable one, and is also met with in the narrow ring-dyke (I) of the Interior Complex. The main body of the rock is a quartz-dolerite, frequently porphyritic, which is almost everywhere riddled with veins of granophyre (Fig. 34). These veins form reticulated patterns recalling the acid veinings characteristic of many intrusive margins in Ardnamurchan and elsewhere, to which the name ‘ intrusion-breccia ’ is applied. But unlike the marginal intrusion-breccias, the ‘ net-veining ’ is found throughout the length and breadth of the mass. It is as abundant on the summit of Sgùrr nam Meann, about a quarter of a mile from the outer margin, as it is close to this margin along the shore to the west. Locally it may be absent, but one cannot go far at any place without encountering it. Similar veining is fairly frequently met with in many of the quartz-gabbros, but is never so strikingly developed as in the present instance. A comparable occurrence appears to be the peridotite mass of the Cuillins, Skye, which Dr. Harker has described as everywhere net-veined, though in this case with a basic magma.[1]

The consolidation of the quartz-dolerite was complete before its brecciation and the injection of granophyre. No mixing of the two magmas is apparent, such as is found in composite intrusions (p. 184). To some extent the granophyre has incorporated small fragments of the quartz-dolerite, as shown by their rounded outlines, and also by the hybrid nature of the granophyre in contact, but the angularity of the blocks of quartz-dolerite is on the whole a striking feature in the field. Though intruded distinctly later than the quartz-dolerite, the granophyre magma must have risen in the same ring-fissure, since, except for stray masses and veinings of granophyre which are locally of common occurrence in the adjoining Hypersthene-gabbro (a), the granophyre is confined to the elongate area occupied by the Quartz-dolerite. The granophyre was certainly not a residual magma derived from the adjacent and later Quartz-gabbro of Loch Caorach (g). This follows because the net-veining on Sgùrr nam Meann is as highly contact altered as the Quartz-dolerite itself, as are also cone-sheets by which the net-veining is cut ; while the adjacent Quartz-gabbro (g) is free of cone-sheets and apparently unbaked. In fact the Quartz-gabbro (g) is concluded to be partly the cause of the contact alteration. On the west side of this hill, a mass of granophyre, apparently part of

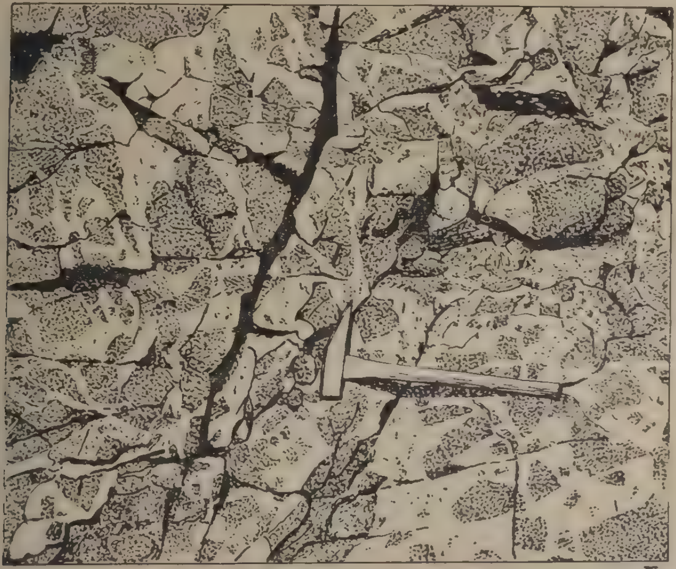

FIG. 34.—*Quartz-dolerite net-veined by granophyre, Sgùrr nam Meann Ring-dyke, on shore south-west of Sgùrr nam Meann.*
Drawn from Geological Survey Photograph, No. C. 2773.

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[1] 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, pp. 77, 78.

the Sgùrr nam Meann intrusion, and perhaps a break-through of granophyre in bulk, is also slightly baked.

It therefore seems necessary to regard the brecciation and subsequent infilling of the cracks by granophyre as due to an uprising granophyre magma that entered the ring-fissure in which the quartz-dolerite consolidated. The brecciation is attributed to explosive gases given off from the acid magma that was injected into the cracks thus formed. So complete is the brecciation over great portions of the Ring-dyke that there is a striking likeness between the resulting veined rocks and volcanic breccias, such as those of Glas Eilean, that have their cracks and crevices infilled by acid tuff (p. 133).

Relations along Outer Margin.—It can be fully demonstrated that the Quartz-dolerite is later than the Hypersthene-gabbro (a) forming its outer wall. West of Beinn na Seilg where the Hypersthene-gabbro is well banded, the banding is cut across by the porphyritic margin of the Quartz-dolerite. The best exposures of this junction are to be found immediately west of a narrow strip of peat-covered alluvium that extends along the course of the more westerly of two N.–S. faults shown on the published geological maps. Here, steeply inclined Inner Cone-sheets are numerous and resemble in type the porphyritic edge of the Quartz-dolerite, but can be easily distinguished from it by their darker weathering hues. A diagrammatic sketch of junctions seen in the face of a cliff about 20 ft. high; along the west side of the alluvium, is given in Fig. 35. Immediately west of this cliff the junction of the two ring-dykes is also well displayed. It may be mentioned that the cone-sheet shown in the figure as almost obliterating the junction is steeper than usual, and is a double intrusion with a central coarsely crystalline portion and porphyritic fine-grained margins. Xenoliths of the Hypersthene-gabbro are found in the marginal portion of the Quartz-dolerite, and corroborate the other evidence of the relative ages of these two intrusions.

Sharp contacts such as that just described are usually a feature of the outer margin of the Quartz-dolerite, as far north as the right bank of the stream east of the Point of Ardnamurchan; but north of this along the shore north-east of the Pier, east of the Lighthouse, the most intricate junctions imaginable occur between the two rocks. The Hypersthene-gabbro appears to be literally honeycombed by the Quartz-dolerite. Still farther north, south of a stream that flows west along a hollow north of Sgùrr nam Meann, there is a semblance of gradation from one rock into the other, through an apparent transition zone some 30 yds. wide. Some portions of this zone consist of what appears in the field to be shattered and acidified hypersthene-gabbro, fairly coarse in grain. Other portions, more especially close to where the Quartz-dolerite occurs, are finely granular, and appear to resemble the Quartz-dolerite. Xenoliths of the latter material are, however, enclosed in the Quartz-dolerite, while perfect gradation may sometimes be seen, in one and the same exposure, from obvious hypersthene-gabbro into the granular rock. A microscopic slice of this granular material shows that it consists chiefly of shattered hypersthene-gabbro that has been subsequently contact altered (24439). North of the stream this belt of shattered rocks is even wider, and, though well exposed, is most difficult to interpret. Coarse augitic gabbros occur in sharp contact with granular gabbros, while much acid veining intensifies the difficulties presented. Adjacent angular blocks enclosed by this net-veining may be of quite different materials, such as augitic gabbro, coarse quartz-gabbro, granular gabbros, and also quartz-dolerite. The locality should repay more study than it has been possible to give to it, but two lessons may be learnt from it. In the first place it illustrates the difficulties that are to be met with in dealing in the field with ring-dyke margins, and shows how an apparent transition from one rock into another may

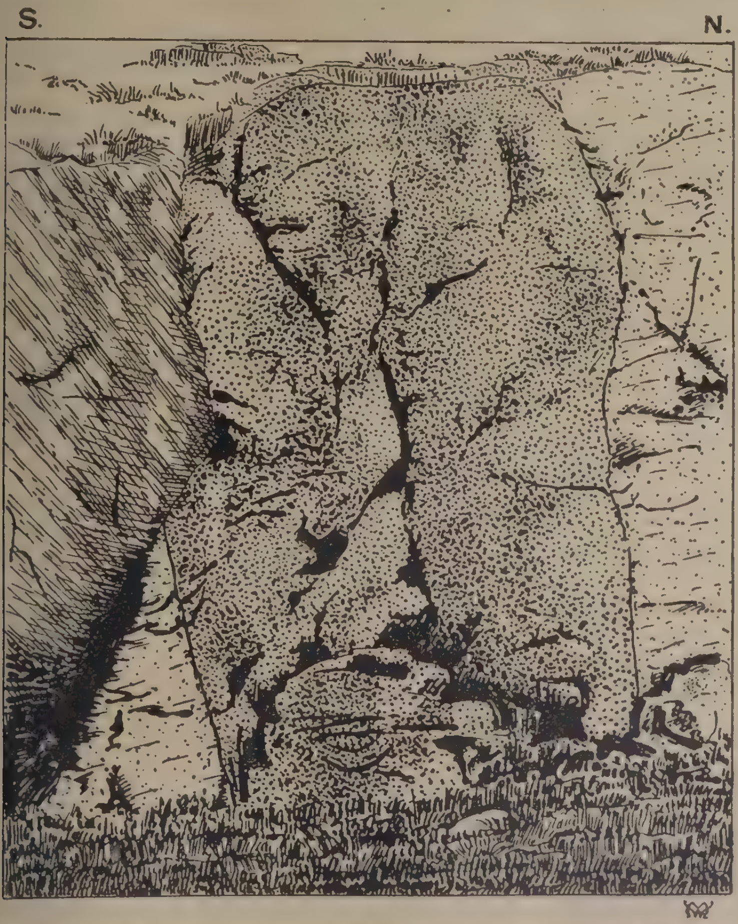

FIG. 35.—*Intrusive Junctions, seen in 20-ft. cliff west of Beinn na Seilg. Hypersthene-gabbro Ring-dyke, banded ornament. Quartz-dolerite Ring-dyke, light stipple. Inner Cone-sheet, heavy stipple.*

be entirely misleading. Similar marginal relations between rocks of similar texture, such as coarsely crystallized eucrite and quartz-gabbro, might render it quite impossible to locate any contact between them. Secondly, the locality affords a good example of intense brecciation affecting the wall of a ring-dyke. The appearance of the brecciated Hypersthene-gabbro suggests brecciation by explosive gases rather than by earth-stresses. The brecciation must, however, have preceded the coming into position of the Quartz-dolerite, since the latter encloses xenoliths of the brecciated rock.

Associated Acid Masses.—Stray masses and sheets of granophyre are found in the Hypersthene-gabbro (a), which may have been derived from the granophyre magma responsible for the veining of the Quartz-dolerite (e). Whatever may have been their origin, they well serve to demonstrate that net-veining can be produced by such a magma. A good example is provided by a westerly inclined sheet of granophyre, which is shown on the published maps north-west of Sgùrr nam Meann. This, and an adjoining sheet, are well exposed at their south ends along coastal cliffs that bound a sandy beach. Reticulating veins of granophyre are abundant in their roofs, and are demonstrably in continuity with the underlying sheet, from which they were evidently injected. These net-veins are more slender, and the brecciation less pronounced, than in the case of the Quartz-dolerite (e).

Xenoliths in these granophyre sheets are of interest. They consist of hypersthene-gabbro, apparently not much altered immediately below the roof, from which they were evidently detached. Farther down, towards the centre of the sheet, they are much metamorphosed, and progressively with depth below the roof become paler in colour and finer in texture, as a result of their impregnation by the acid magma. If an opinion had to be based on their composition alone, the origin of these altered xenoliths might indeed be difficult to surmise.

The granophyre itself is more or less hybridy in character throughout (21520). Usually, contacts with its roof are sharply defined, but at one point in the more southerly sheet the granophyre is much basified for an inch or two from the gabbro (24437), into which it thus appears to merge. J.E.R.

Petrology.—The description of this Ring-dyke given above indicates that we are here dealing with a variable, moderately basic intrusion that has been shattered and injected in a most intricate manner by acid material of granophyric composition. In this mass not only are we confronted with the effects of assimilative processes acting upon the basic material, but, in addition, have the superimposed results of contact metamorphism due to adjoining later intrusions.

The basic mass, where least shattered and permeated with granophyric matter, is a moderately coarse ophitic dolerite with abundant ilmenite (22630) and with labradorite as the dominant felspar. A certain amount of interstitial granophyric matter is always present and occurs sometimes in such a manner as to suggest that it was an original constituent ; and this fact, coupled with the general absence of olivine, is in favour of the rock being in part at least a true quartz-dolerite or quartz-gabbro.

The whole mass, however, has suffered an invasion by an apatite-rich granophyric magma that in the cases of veination has been accompanied by slight local assimilation. In more extreme cases a fine-textured blotchy rock has resulted, to which the term hybrid is undoubtedly applicable. In the former case the basic rock although brecciated retains its original basic character, and the acid material is restricted to the vein-like infillings. In the other case the basic rock has almost completely lost its individuality, such fragments as remain are swamped in a heterogeneous mass that is neither gabbro nor granophyre but clearly results from the contamination of an acid magma by basic material that has been incompletely absorbed. All stages of basification of the acid magma can be studied.

Considering the veined gabbro first, in which the basic rock was solid and relatively cool before the injection of the acid magma, we find that where actual veins can be seen to traverse the rock either as filaments (24169) or as a network of coarser structure, such veins are either granophyric or felsitic in character. They usually carry a little biotite (22346) as the chief ferromagnesian mineral and this increases in amount, in the wider veins, towards the contact with the basic rock. The margins of such veins are often quite indefinite and contain abundant pyroxene in granules and small idiomorphic crystals (22279). The basic rock itself is, in such cases, of a hybrid type with resorbed augite and felspars.

The larger veins (24437) exhibit interesting contamination phenomena. They are commonly basified with the separation of abundant pyroxene in small idiomorphic crystals (24437), while the basic rock contains recrystallized augite together with hypersthene, the latter often in large subophitic plates.

Many of the apparently homogeneous, fine-grained portions of this ring-dyke are certainly not normal rocks and must result from the complete assimilation of basic material by acid magma. They are composed of more or less fine-grained rocks that consist of pyroxene, regrown and albitized moderately basic plagioclase, iron-ore, and a residuum of alkali-felspar and quartz. The monoclinic pyroxene has usually recrystallized with a tendency towards idiomorphism, but the outstanding feature is the general prevalence of a rhombic pyroxene (22409), which may be regarded as the natural outcome of acidification (Fig. 33 B, p. 248). The rhombic pyroxene is frequently pseudomorphed (23588). The larger felspars are mainly a labradorite of gabbro origin. They have suffered resorption and irregular regrowth as well as local albitization, while physical effects such as bending and fracture are often discernible. Fresh small felspars of less basic composition result from recrystallization. Augite occurs both as a product of recrystallization and as partially resorbed *remanié* crystals. This resorption is a familiar feature and is always accompanied by a granulitization or regrowth, together with the separation of microscopic magnetite. The recrystallized augite is frequently idiomorphic and endeavours to assume a columnar habit.

Apatite is practically restricted to the acid mesostasis, and to such areas of the basic rock as, by their recrystallization and modification, show the influence of the invading acid magma.

With a still further increase in the amount of acid material the acid mesostasis usually present (23588–9) becomes obviously in excess, and imparts to the rock a lighter colour and more speckled appearance. The microscope in such cases shows that there has been intense marginal modification of the older felspars with regrowth upon them of wide irregular borders of albite-oligoclase. They are locally albitized, and penetrated and embayed by micrographic orthoclase and quartz. The original pyroxene has undergone almost complete absorption and its place has been taken by freshly formed granules and crystals of both monoclinic and orthorhombic varieties (23597). There has been the usual attendant separation of magnetite. The amount of acid mesostatic material is fairly large and has a micrographic structure. Where this material is in contact with older constituents the corrosive effect is well marked (23590–2), sometimes including the formation of biotite (22350, 24436).

Metamorphism by the Quartz-dolerite. The metamorphic effects attributable to the intrusion are most noticeable in the Hypersthene-gabbro (p. 258) which forms its outer margin, and in the xenolithic masses of this rock which it encloses. They are primarily intense shattering of the older gabbro followed by a granulitization of the ferromagnesian and felspathic constituents (24437, 24439).

Within the intrusion, in addition to the usual granulitic gabbros, etc., certain dark xenolithic masses, noted to the north-west of Sgùrr nam Meann, have a banded structure and abnormal composition. In thin section (24440) the darker bands are seen to be composed mainly of dark-green spinel, as crystals that range up to a quarter of an inch in size, set in a matrix of magnetite (Fig. 32 B, p. 234); lighter bands of no great thickness contain the same spinel in small crystals that are scattered through a mass of small twinned crystals of basic plagioclase felspar (bytownite-anorthite). Contrary to expectations the rock contains no cordierite, but a little biotite is present in the more felspathic areas and is due presumably to interaction between ferriferous and felspathic constituents.

The origin of these xenolithic masses is obscure and the abnormality of their composition difficult to interpret. It is hard to regard them as being cognate to the gabbro, although rocks with a similar spinellid have undoubtedly been formed by the reheating of basic gabbroic segregations (p. 317). It is a well-known fact that the re-fusion of an anorthite-olivine segregation, such as might reasonably be expected in connexion with certain of the gabbro masses, would yield spinel, which, in a gabbro-melt might concentrate sufficiently to form such spinel-rich masses as are occasionally encountered.[1]

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[1] O. Anderson, 'The System Anorthite-Forsterite-Silica,' *Amer. Journ. Science*, vol. xxxix., 1915, p. 407.

It may be, however, that they have resulted from the metamorphism of some highly ferriferous and aluminous rock of sedimentary origin, which has been modified by the diffusion of lime from the gabbro magma. There is some likeness, in the association of the green spinel (pleonaste-hercynite) with basic plagioclase, to the assemblage exhibited by the spinel-bearing accidental xenoliths of the Loch Scridain sills in Mull.[1]

Metamorphism of the Quartz-dolerite.—Such alteration as the Quartz-dolerite has itself undergone is in part attributable to the Quartz-gabbros (g) and (g′) that are intruded along its inner margin, and in part to the influx of hot acid magma forming the net-veins. Its metamorphism next to the Quartz-gabbro (g′) takes the form of granulitization in specimens collected west of Beinn na Seilg (23591, 23592, 23637). But, that much of the metamorphism was accomplished after the injection of the rock by acid magma is quite obvious. It is easy to detect the effects of hybridization and see that these have been followed in most instances by a general granulitization of both basic and acid material (23591, 22279). Such is noticeable also near, or at, the contact of the mass under description with the Quartz-gabbro of Loch Caorach (g) where the rocks have been both acidified and granulitized (22633, 23635, 24435). The metamorphic influence of later intrusions can be detected even in the acid veins, which also share in the granulitization (22346).

Cone-sheets cutting the Quartz-dolerite.—Such cone-sheets as are encountered within the Quartz-dolerite belong to the Inner Set of Centre 2 and are mainly porphyritic dolerites (p. 192). Others of quartz-dolerite composition and referable to the Talaidh type (22347) are met with on the summit of Sgùrr nam Meann where they have experienced considerable metamorphic changes (p. 292). Their finer-grained constituents have been recrystallized and a general granulitization has extended throughout their mass. A microporphyritic type is here also represented (21521) containing small porphyritic crystals of augite and plagioclase felspar in a fine-textured quartz-doleritic matrix that has been more or less completely granulitized. H.H.T.

(f) EUCRITE OF BEINN NAN ORD

Like other Ardnamurchan eucrites, this intrusion is highly durable, and for the most part forms higher ground than quartz-gabbros on either flank. The craggy northern summit of Beinn na Seilg, for example, is composed of a narrow inwardly projecting arm of the Eucrite (Fig. 36 and Pl. VI). The elongate ridge of Beinn nan Ord also owes its shape largely to the Eucrite that is well displayed in steeply rising crags on its south-west side. The valley between these two hills, where crossed by the Eucrite, has followed the course of N.–S. lines of crush. Northwards of Beinn nan Ord the intrusion also extends along lower ground, but here its deterioration in durability may be, in part at least, attributed to its intensely brecciated condition.

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[1] H. H. Thomas *in* 'Tertiary Mull Memoir,' 1924, pp. 274–278.

Most usually, olivine is abundant and the rock practically an allivalite, but augite-rich types also occur. From a point eastward of Sgùrr nam Meann northwards to the south shore of Sanna Bay, an augitic type predominates, the augite forming large plates. An intermixture of the two types may be seen in the more northerly of the two inwardly projecting arms of the intrusion, west of the Allt Grigadale. There, small rounded masses of coarsely ophitic augite-rich eucrite occur in an allivalitic matrix. The masses may perhaps be in the nature of cognate xenoliths. East of Sgùrr nam Meann, in addition to the type with large augite plates, acidified gabbro or eucrite has been included as part of the intrusion. The acidification seemed to be an original character of the rock. The Eucrite, whatever its composition, varies much in grain and often quite abruptly. Fine-grained xenolithic material is a frequent feature. It usually forms streaks and layers drawn out and often contorted by flow-movements, as may be seen along Beinn nan Ord, and on the east side of the valley immediately east of this hill. It weathers with a reddish hue, as though olivine-rich, and is cognate to the Eucrite, as is shown by microscopic examination (21576). Xenolithic material in regular-running bands is prevalent along the south shore of Sanna Bay, and is frequently traversed by acid veins. It has the appearance of being granulitized quartz-

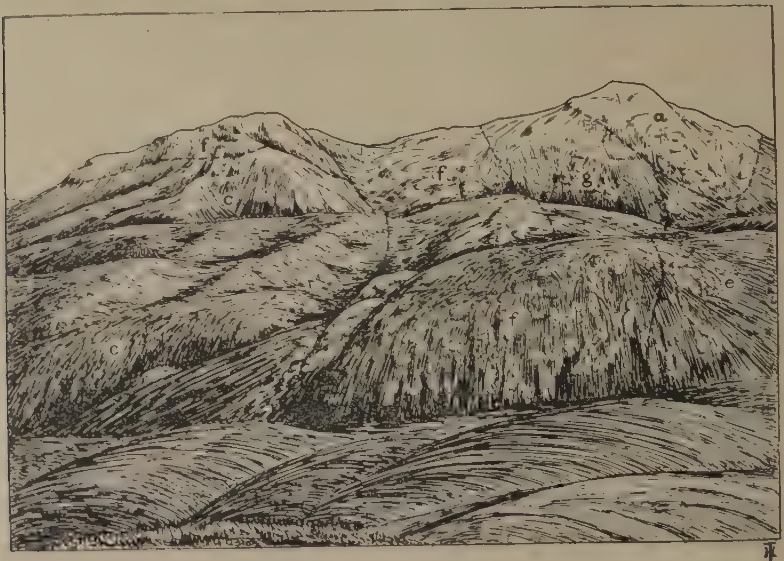

Fig. 36.—*View of the western side of Beinn na Seilg.*

a, *Hypersthene-gabbro.* c, *Quartz-gabbro of Garbh-dhail.* e, *Quartz-dolerite of Sgùrr nam Meann.* f, *Eucrite of Beinn nan Ord.* g′, *Quartz-gabbro of Beinn na Seilg. Broken lines indicate margins of ring-dykes (not shown in foreground).*

dolerite, and the single specimen sliced bears a resemblance to the Talaidh type characteristic of the cone-sheets (24173).

The dyke-like form of this intrusion is perhaps better displayed than by any other ring-dyke in Ardnamurchan. But, even in this instance, there is nowhere sufficient depth of section to allow us to conclude what may be the prevailing inclination of its walls. The intrusion is exposed to a depth of about 600 feet on the sides of the valley separating Beinn na Seilg from Beinn nan Ord. The view from Beinn nan Ord across the valley, with its minor ridges and hollows, due to erosion along crush-lines, shows how abruptly the margins of the Eucrite cross all these surface irregularities (Fig. 36). The view looking towards Beinn nan Ord is equally striking, for the Eucrite extends straight up this steep hillside to the summit of the ridge, 300 feet above the level of the stream-course at its base.

It is noteworthy that the two inwardly projecting arms of the Eucrite are directed towards the Aodann Centre. Both arms can be proved by practically unbroken outcrops to be continuous with the main mass. The more southerly arm, that forms the north summit of Beinn na Seilg, is dyke-like in form, and not a sheet-like tongue; for its intrusive margin against the Quartz-gabbro of Garbh-dhail (c) is practically vertical, where seen on its west side just north of its bifurcation from the main mass. These arms appear to mark the position of radial fissures in continuity with the main ring-fissure. The only other instance of such an occurrence in Ardnamurchan is a radial prolongation from the outer side of the Quartz-dolerite Ring-dyke (I) of the Interior Complex, to the north of Meall Meadhoin (*see* Memoir-map).

Age Relations.—There is a considerable amount of evidence to show that the Eucrite is later than the Garbh-dhail Quartz-gabbro (c), which accompanies it along much of its inner margin. Along the east slope of Beinn nan Ord the Quartz-gabbro (c) is traversed by abundant shear-lines and by bands of black flinty crush-rock. These are in turn crossed by a plexus of basic sheets, quite uncrushed, some of which at least belong to the Inner Cone-sheet Complex. None of the sheets penetrate the adjoining Eucrite, nor is linear crushing apparent in the latter. Similarly, the inwardly projecting arm of the Eucrite, forming the northern half of Beinn na Seilg, is not crossed by a single cone-sheet, though on its east side cone-sheets traversing the Quartz-gabbro can be actually traced to within a few feet of its margin. Along the western side of this arm, the Quartz-gabbro is in an absolutely comminuted condition (24447) next to perfectly sound Eucrite (24446). It proved difficult in the field to fix exactly the contact of the two rocks, for the brecciation causes the Quartz-gabbro, which contains olivine, to appear not unlike the fine-textured Eucrite. A definite contact, however, was located on the hill-slope, just east of the stream east of Beinn nan Ord. The Eucrite there becomes finer grained and fluxioned at its contact with the fine-grained baked margin of the Quartz-gabbro (24449). As already stated (pp. 242-3), this fine-grained marginal facies of the Quartz-gabbro in a highly baked condition extends all along the outer margin from Beinn na Seilg to the northern end of

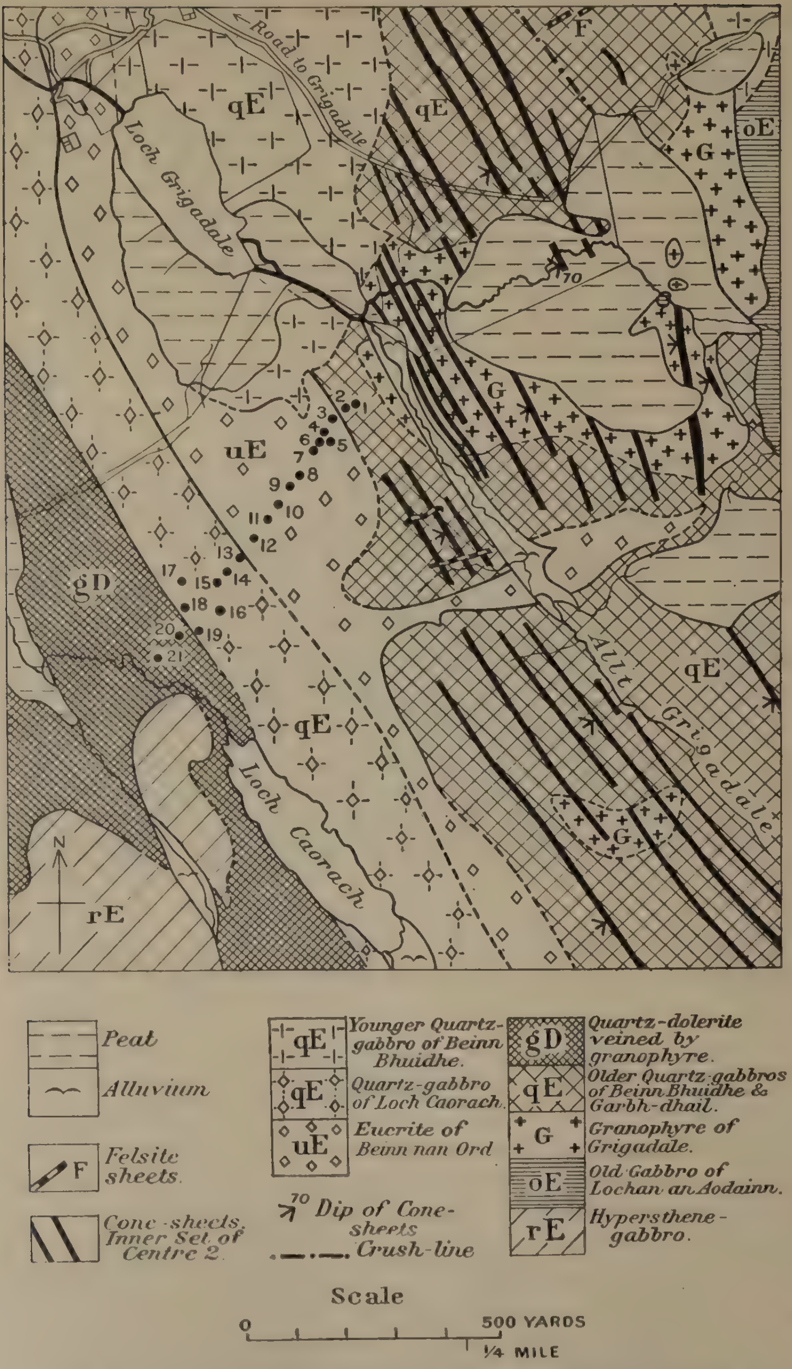
Road to Grigadale
Loch Grigadale
qE
F
oE
G
70
uE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
gD
Allt Grigadale
Loch Caorach
N
rE
Peat
Alluvium
F Felsite sheets.
Cone-sheets, Inner Set of Centre 2.
qE Younger Quartz-gabbro of Beinn Bhuidhe.
qE Quartz-gabbro of Loch Caorach.
uE Eucrite of Beinn nan Ord
70 Dip of Cone-sheets
Crush-line
gD Quartz-dolerite veined by granophyre.
qE Older Quartz-gabbros of Beinn Bhuidhe & Garbh-dhail.
G Granophyre of Grigadale.
oE Old Gabbro of Lochan an Aodainn.
rE Hypersthene-gabbro.
Scale
0
500 YARDS
¼ MILE

Fig. 37.—*Map of portion of Ring-dyke Complex of Centre 2, north of Beinn nan Ord.*

Note.—Localities of a serial collection of rock-specimens are indicated by black dots numbered 1–21 (*see* pp. 268–270, 274, 275).

Beinn nan Ord, and forms the actual summit of the Beinn nan Ord ridge. The baking appears most intense next to the Eucrite, which contains xenoliths of a similar rock at a point on the ridge opposite the north end of Loch Caorach. In addition, at this place, non-porphyritic grey felsite occurs in irregular sheets and dykes cutting both the sheared Quartz-gabbro and the unbroken porphyritic cone-sheets that traverse it (p. 280), and felsite of the same type cuts the baked fine-grained margin of the Quartz-gabbro next to the Eucrite, and seems in the field to be baked to a like degree—an appearance confirmed by the microscope (24401, p. 281). There is thus sufficient evidence to prove that the Eucrite is later than both the Garbh-dhail Quartz-gabbro and the Inner Cone-sheets.

Subsequently, as it appears, to the intrusion of the Loch Caorach Quartz-gabbro (g), the Beinn nan Ord Eucrite was shattered along a portion of its length, from Beinn nan Ord northwards to Sgùrr nam Meann. Microscopic examination shows that the Quartz-gabbro (g) at one point at least is similarly affected. The minute brecciation of the crystals can be seen with a pocket lens, while under the microscope, Dr. Thomas finds that these shattered rocks have been subsequently granulitized. Further details will be given below in the petrological section, and the significance of the brecciation has been already referred to (p. 214). It may here be stated that the shattering is quite different in character to the linearly directed crushing found near by in the Garbh-dhail Quartz-gabbro. The shattering seems due to the explosive action of gases, for some reason almost entirely confined to the Eucrite, the crushing to earth-stresses. J.E.R.

Petrology.—The Eucrite of Beinn nan Ord, where it outcrops on the foreshore of Sanna Bay (21556), is a moderately coarse-textured rock composed of fairly abundant olivine, an ophitic greenish-brown augite associated with large crystals of iron-ore, and somewhat elongated interlocking crystals of basic plagioclase.

The olivine is mainly fresh, almost colourless in thin section, and free from inclusions; when decomposed it has passed into an aggregate of magnetite and talc, which demonstrates its ferruginous and magnesian nature. As usual, it is commonly associated with a little biotite and also develops peripheral hypersthene. The felspars range from labradorite to bytownite, and for the most part exhibit a fine schillerization due to parallel orientated opaque hair-like inclusions. The augite frequently shows a schiller structure that is probably original, but the similar structure in the felspar is more likely to have been superinduced as the result of metamorphism.

To the west of Grigadale (22634), the rock locally shows abundant signs of shattering, followed by granulitization and acidification. Remnants of original augite and basic plagioclase still remain, but much of the augite has been recrystallized. The introduction of acid magma has resulted in the widespread crystallization of alkali-felspar and small patches of quartz and orthoclase in graphic intergrowth.

A little farther to the south, west-south-west of Grigadale, the mass to a great extent resumes the normal character of an olivine-rich eucrite (24171), with subordinate diallagic augite and a little biotite and hypersthene in association with the olivine. At the same time, however, local acidification and the consequent separation of strings and patches of granophyric matter (22678) are attendant conditions. Similarly, to the west of Loch Grigadale, a coarsely ophitic augitic type, relatively poor in olivine, shows marked albitization (24170) and schillerization of the felspars, together with a recrystallization of granulitic augite.

South of Grigadale the ring-dyke is composed almost entirely of the usual olivine-rich variety of eucrite, but it presents features that were only feebly represented farther to the north. From the neighbourhood of Loch Grigadale southward towards Beinn na Seilg, the eucrite has been profoundly shattered by the explosive activity of a subterranean magma, and subsequently metamorphosed with the occasional introduction of acid magmatic matter.

A careful traverse (Fig. 37, p. 266) was made by Mr. Manson south-westwards from the Grigadale Granophyre (c′) across the outcrops of the Eucrite and of the rocks that bound it on either side, in order that all variations of the Eucrite, both as regards texture and type, might be collected. It was found that almost the whole mass of eucrite (22391–4; 3–12 of Fig. 37) along this line was of an olivine-rich nature and approached an allivalitic composition. But, it had suffered throughout its whole mass an intense shattering that had broken up the larger crystalline elements and reduced the rock to a thoroughly fragmental condition. Subsequently to the shattering a recrystallization and granulitization was impressed upon the mass; processes that in a measure healed the scars, but failed to obliterate completely the kataclastic structure. Further, it is obvious from the acid outgrowths upon the shattered basic felspars, and also from the occasional introduction of granophyric matter between the crystal-fragments, that a granophyre magma was responsible for the shattering and subsequent metamorphism.

Close to the northern margin of the Eucrite an olivine-dolerite, the marginal portion of the Quartz-gabbro (c), shows some signs of disruption. Its main feature, however, is the manner in which it had been injected with acid magma that had consolidated as a fine aggregate of alkali-felspar and quartz, charged with minute needles of apatite (22390, 2 of Fig. 37). This apatite-rich acid magma had albitized the basic felspar with which it came in contact, and produced less basic growths upon the felspar-fragments.

Followed along the line of the traverse, this type gives place in a few yards to a somewhat augitic eucrite with large crystals of olivine set in a matrix of somewhat broken up and regrown labradorite-bytownite felspar, recrystallized augite, rhombic pyroxene, and subordinate iron-ore. Thermal metamorphism of late date is suggested by the transformation of chloritic aggregates to biotite.

From this point onward, the shattering of the eucrite becomes more intense and reaches a maximum about the centre of the outcrop. Nearly every individual crystal of original formation has been separated from its fellows (22392; 4 of Fig. 37) and broken up, so that the larger fragments lie in a fine matrix that consists now of a granulitized mass of broken felspars and recrystallized augite. The fine-grained fragmental matrix has responded most readily to the metamorphic influences and has been also acidified to some extent, for, although there is often no actual interstitial acid material, the felspars have regrown with a generally more acid composition. One of the results of metamorphism is particularly noticeable in the olivine, which in all the eucrite of this region has assumed a highly characteristic schiller-structure (22393, 5 of Fig. 37). It gives the mineral a grey tint by transmitted light and is due to the separation of minute rod-like inclusions arranged in two planes parallel to the cleavages (010) and (100).

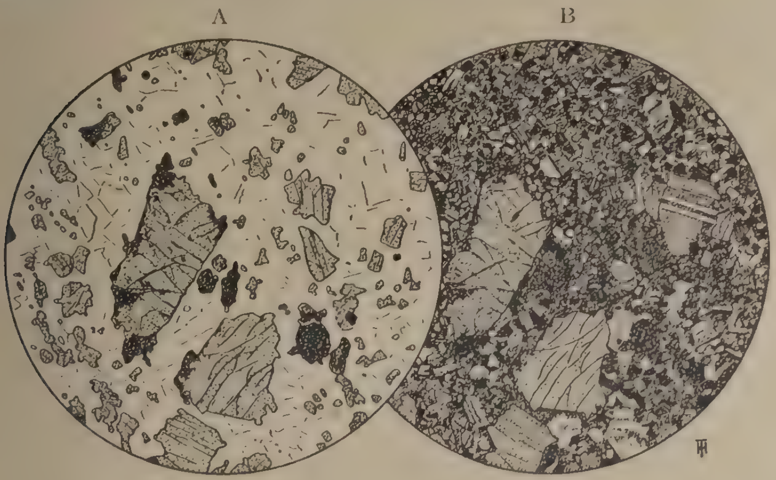

FIG. 38.—*Eucrite of Beinn nan Ord.*

A. (22397)×20. *Irregularly bounded and broken crystals of olivine with some augite in a felspathic matrix. Ordinary light.*

B. (22397)×20. *The same field between crossed nicols, showing the shattered character of the matrix. Subsequent metamorphism attended by recrystallization has, to a certain extent, reduced the original intensity of the cataclastic structures.*

Occasionally, portions of the mass lying between shattered belts have escaped disruption (22394; 6 of Fig. 37), but by far the greater part of the rock exhibits shattering followed by granulitization (22395–6; 7 and 8 of Fig. 37). The most intense shattering of all, however, is observed about the centre of the Eucrite outcrop (22397; 9 of Fig. 37), where the original rock has been broken down in a most complete manner before recrystallization set in (Fig. 38). The larger felspars are shattered and partly albitized, original large augite-crystals have been broken and their cleavage-traces flexed, while even the olivine, which often escapes disruption, is broken up and occasionally granulitized (22398; 10 of Fig. 37).

Certain more augitic varieties of the Eucrite (22399; 11 of Fig. 37), which more properly come under the heading of gabbro, occur in the traverse, towards the southern boundary of the Eucrite. In addition to the effects of shattering, they may show the general acidifying influence of an invading magma by the albitization of the basic plagioclase and the development of interstitial alkali-felspar. Actually at the margin of the Eucrite, specimens were collected which appear to have escaped shattering and which, apart from subsequent granulitization, are normal olivine-rich eucrites (22400; 12 of Fig. 37).

Another traverse was made farther south across the outcrop of the Eucrite on the northern slope of Beinn nan Ord, north-east of the south end of Loch Caorach. The specimens collected indicate that the rock here is of the same olivine-rich type as previously noted. The olivine is fresh but schillered, and the amount of augite somewhat variable. In some instances augite is feebly represented (22413), but in others it plays an important part in the mineral-composition (22411).

The shattering that was such a marked feature of the Eucrite farther north is still present, and in some cases is intense (22414); as before, it has been followed by the healing process of granulitization, and there are instances of actual penetration by acid magma (22419). To the west, towards Beinn na Seilg, the Eucrite is seemingly less shattered, but exhibits extensive albitization of its felspars. Just to the west of Beinn na Seilg, and close to its southern margin, the Eucrite is an augite-rich rock that appears to have undergone some modification (22677). It has a roughly banded structure, is moderately fine-grained, and is composed about equally of augite and plagioclase. The augite has a greenish tinge, is hypidiomorphic, and is remarkable for an almost constant simple twinning parallel to (100).

The felspar is much twinned but practically unzoned labradorite of medium basicity. It is possible that the rock here is in a modified condition, for occasionally there is obvious penetration by acid magma that has enveloped and attacked the older gabbro constituents (24450), and left an interstitial residuum of alkali-felspar and quartz in graphic intergrowth.

A review of the microscopic evidence is in favour of the marked disruptive effects noticed in the Beinn nan Ord Eucrite being due to an explosive shattering of the rock by a subterranean acid magma. There is very little evidence of true crushing due to earth movement, and only a single thin band of flinty crush-rock, such as is so prevalent in the neighbouring Quartz-gabbro of Garbh dhail (c), has been encountered in the Eucrite on Beinn na Seilg (21472). It is composed of finely comminuted felspar and augite through which pass fluxion bands of opaque material containing drawn-out whisps of felspar and augite.

A very interesting enclosure in an inwardly projecting portion of the Eucrite occurs east of the Allt Grigadale, half a mile south-east of Loch Grigadale. It is a fine-grained rock composed of olivine, augite, and labradorite with scattered crystals of magnetite. Olivine occurs, as in the Eucrite, as fairly large irregularly bounded crystals, but is not abundant. Augite is plentiful as ill-formed crystals that look like broken fragments of larger individuals. The felspar is present as somewhat elongated small crystals of oligoclase-andesine composition and appears brown by transmitted light owing to a superabundance of minute inclusions. The rock has all the appearance of a hybrid, and also of having suffered reheating with attendant schillerization of the felspar. H.H.T.

(g) and (g′). Quartz-gabbros of Loch Caorach and Beinn na Seilg

These two masses are grouped together in Pl. V as portions of a single ring-dyke, which in all probability they are. They will be separately referred to in this description, chiefly because they differ in rock-type. The Loch Caorach Quartz-gabbro is practically everywhere a characteristically grey-black gabbroid rock dappled with white spots and patches of acid residuum. Its black hue is to be correlated with its schillerized plagioclase felspar (p. 274). The Beinn na Seilg Quartz-gabbro is a coarse-textured speckly black and white rock that closely resembles the neighbouring Eucrite, but differs in containing a small though definite amount of acid mesostasis and large crystals of iron-ore, and in possessing little olivine. The boundary between the two types coincides roughly with the hollow between Beinn nan Ord and Beinn na Seilg.

The main interest of these Quartz-gabbros lies in their relation to the Quartz-dolerite (e) and Eucrite (f) that accompany them on either flank. The evidence of their relative ages is set out below and seems to establish the later age of the Quartz-gabbros, though the finding of more contacts is perhaps to be desired. The outer margin of the Loch Caorach Quartz-gabbro against the Quartz-dolerite (e) was located south of Sgùrr nam Meann, about 100 yds. north of the track that runs from Grigadale to the Lighthouse. The Quartz-gabbro is quite a coarse-grained rock about 25 yds. from the margin, and of the characteristic black colour with spots of acid material. Close to the margin it changes to a relatively fine-grained quartz-gabbro, which is strung with coarser augite-rich gabbro and veins of gabbro-aplite. The augite-rich strings look like thin pegmatite-veins. Both kinds of veins run parallel to the margin. They are evidently marginal features, and are probably the infillings of contraction-cracks developed in the cooling rock. The Quartz-dolerite alongside carries abundant felspar phenocrysts, but a tendency to porphyritic structure is also found in the marginal quartz-gabbro. The issue is thus complicated. Sharp junctions of the marginal quartz-gabbro and the porphyritic quartz-dolerite could however be made out. The latter rock has the appearance of being greatly baked, and this has been confirmed on microscopic examination by Dr. Thomas (22633).

North of Sgùrr nam Meann, the line of demarcation between the two rocks can be traced vertically down the steep, north side of an east-west gully. The Quartz-dolerite, lighter coloured on weathered surfaces and evidently the more acid rock, ends off abruptly against the darker Quartz-gabbro, which is a coarser-grained basic-looking rock with acid spots. Yet, though the distinctness of the two rocks is evident, their actual contact is most difficult to locate. A junction specimen was collected from one point on the side of the gully, showing quartz-dolerite in contact with somewhat fine-grained quartz-gabbro, and under the microscope the quartz-dolerite appears to be the older rock (24438). Acid net-veining is a feature of the Quartz-gabbro close to its margin. Cone-sheets that cut the acid-veined Quartz-dolerite are present north of Sgùrr nam Meann and also on the summit, where specimens collected prove that both cone-sheets and acid-veined Quartz-dolerite are highly baked (21521, 22347). The alteration is no doubt in part due to the Quartz-gabbro, which shows no signs of contact alteration. The outcrop of the Quartz-gabbro, however, is interrupted, as though the intrusion were running underneath Sgùrr nam Meann, and this hill is bounded to the east by the Eucrite of Beinn nan Ord. Probably, therefore, the Eucrite may also have been concerned in effecting the unusually intense alteration of the Quartz-dolerite. Mention may be made of rude columnar jointing developed in the Quartz-dolerite on the east side of Sgùrr nam Meann, and inclined east at 45 degrees. This appears to be the result of the baking, and may be compared with jointing found in the much baked capping to the Quartz-gabbro (A) on Meall an Tarmachain (p. 286).

The Quartz-gabbro of Beinn na Seilg (g′) is certainly a separate intrusion from the Quartz-dolerite (e), since the two part company west of the southern summit of Beinn na Seilg, and run one to the north, the other to the south of this peak, which is formed of the Hypersthene-gabbro (a). To the west, where they come into contact, just east of a strip of peat-covered alluvium, the Quartz-dolerite becomes dull black in colour on fractured surfaces, and baked in appearance, next to the fine-grained margin of the Quartz-gabbro. This quartz-dolerite is found by Dr. Thomas to be granulitized (23637).

The relationship between the Loch Caorach Quartz-gabbro and the Beinn nan Ord Eucrite is obscured along a large part of their mutual contact by the brecciation that affects not only the Eucrite but also the adjoining portion of the Quartz-gabbro (p. 267). At one point, north of Loch Caorach, an unbroken junction was located, at which the Quartz-gabbro becomes finer in grain towards a sharp contact with the Eucrite. The junction is seen on the east side of a slight hollow about 80 yds. south-east of a stream and fence shown on Fig. 37, p. 266, and 500 yds. north of the north end of Loch Caorach. More continuous rock-exposures are available along the rocky southern shore of Sanna Bay; and yet, though the two gabbros are here of contrasted types, their actual contact could not be determined satisfactorily. A vague line of junction could be seen, but there was no indication to the eye as to which rock was intruded first. It would appear as if there was little difference in age between them, and that one injection followed closely upon the other. On the other hand, the rocks were not examined microscopically, and it is possible that brecciation similar to that which obscures the contact of these intrusions on Beinn nan Ord, and which is difficult to discern with the unaided eye, may be responsible for the vagueness of the junction on the shore.

In the same way, between the Quartz-gabbro of Beinn na Seilg and the Eucrite (f), junctions are very difficult to locate, and in this case there is the further difficulty that the two rocks are very similar. At the base of the steep west face of the central mass of Beinn na Seilg, there appears to be a contact at which quartz-gabbro cuts eucrite, and the boundary line was traced from there straight up the hillside (*see* Fig. 36, p. 264). J.E.R.

Petrology.—Like most of the so-called quartz-gabbros of Ardnamurchan, this mass exhibits considerable variation, more particularly in the amount of acid material of late consolidation, and in the effects of this partial magma upon the earlier-formed constituents. In addition, however, there are mineralogical variations that are presented by those portions of the mass which are more than normally rich in aluminous pyroxene and iron-ore. Traverses were made across the outcrop of the ring-dyke, one over the low ground to the west of Beinn na Seilg and another southwards from Grigadale. The result of this serial collection has been to emphasize the variability of the mass and to show that different varieties are not restricted in their occurrence. Similar rock-types and variations are encountered in the Older Quartz-gabbro of Beinn Bhuidhe (p. 249) and are closely paralleled by those of the Beinn Bheag gabbro of Mull.[1]

In its most basic or least modified form, as on the western flank of Beinn na Seilg, the magma has crystallized as an olivine-gabbro of eucritic affinities (21503). The rock is of medium texture, grey colour, and is composed of olivine, augite, and a basic labradorite with subordinate iron-ore. The olivine is usually decomposed, but its pseudomorphs are often easily detected and show that the original mineral was an iron-magnesian variety, which frequently occurred in close association with hypersthene. In much of the mass, however, olivine is wanting. In some cases its former presence may be inferred, but in others it does not appear to have existed as an original constituent.

The whole mass exhibits signs of general reheating which are partly textural, partly mineralogical in character, such as granulitization and the respective destruction or production of schiller-structures in augite and felspar. In addition the mass has been profoundly affected by the introduction or migration of an acid magma that has produced both structural and mineralogical changes in the earlier-formed and more basic constituents. This acid magma, rich in alkalis and volatile matter, has in certain cases hybridized with the earlier crystallizations, and where in excess has formed an unmodified mesostasis of alkali-felspar and quartz. Compared with true hybrids, in which there has been more or less complete commingling of magmas and the development of new minerals such as biotite, hornblende, etc., the effects of the acid magma in the case of the Loch Caorach gabbro are of a less intense nature. The phenomena are chiefly those of resorption and recrystallization, closely associated with general albitization. An explanation of this difference, which is also applicable to other quartz-gabbro masses, is probably forthcoming if we assume that the original rock was for the most part solid and relatively cool before the migrating acid magma invaded it. Such an explanation would also account for the rapidly changing relative proportions of acid and basic material.

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[1] H. H. Thomas *in* 'Tertiary Mull Memoir,' 1924, p. 256.

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The shattering that was so marked a feature of the Garbh-dhail gabbro (c), and to a less extent of the Beinn nan Ord Eucrite (f), is reproduced in the Loch Caorach gabbro to a limited degree, and is more particularly a feature of the Beinn na Seilg gabbro (g′) to the west of Beinn na Seilg. The phenomena are of a similar character to that met with in the Eucrite (f), and in extreme cases consist of intense shattering of the original basic felspars followed by albitization and a general granulitization. Where less pronounced, the shattering is restricted to bands traversing otherwise sound rock, and the granulitization has then only affected the more finely comminuted material.

At the northern end of its outcrop, on the flanks of Sgùrr nam Meann (23638), the gabbro is a moderately coarse rock containing pseudomorphs after olivine in magnetite and talc, which are associated with hypersthene. The felspars are turbid and schillerized. They have been resorbed and albitized while the original brownish diallagic augite has been deschillerized locally with a further production of rhombic pyroxene. The rock carries an abundance of acid mesostasis that has been largely responsible for the albitization of the older felspar, and other mineral changes, and has itself crystallized as an interstitial feathery mass of alkali-felspar and quartz.

To the west of Grigadale (23639) the mass is somewhat more augitic, but the felspars exhibit the same schillerization and albitization accompanied by a granulitic development of hypersthene, hornblende, and magnetite in small patches within them. A somewhat similar type occurs close to the Beinn nan Ord Eucrite, to the west of Beinn nan Ord (21483).

A traverse made across the outcrop to the south of Loch Grigadale yielded a series of specimens which exhibits well the explosive shattering that the mass has suffered, together with the adjoining Eucrite of Beinn nan Ord (p. 268). The rocks are predominantly augitic, although olivine pseudomorphs may occasionally be detected (22406; 17 of Fig. 37). The shattering has been followed by albitization of the basic felspars and by a recrystallization of augite (22401; 13 of Fig. 37), also by a general granulitization of the comminuted material (22402; 14 of Fig. 37). Where the shattering does not affect the whole rock it is often possible to detect narrow zones along which disruption has taken place (22403; 15 of Fig. 37), and which have had their fine-grained material more or less completely granulitized. All these rocks have recrystallized augite that exhibits slightly different characters from the original mineral. The main differences are that the new augite is free from schiller-structure, tends towards idiomorphism, and is of a distinctly greenish hue, due, no doubt, to the introduction of alkalis from the migrating acid mesostasis. The acid quartzo-felspathic, and frequently micrographic, material is often abundant and quite impartially distributed (22407; 19 of Fig. 37), but in some cases is definitely segregated into veins (22408; 18 of Fig. 37).

Another traverse made about half a mile to the west of Beinn na Seilg demonstrated that the mass is there of similar constitution. The rocks are medium to coarse-textured gabbros that carry hypersthene (22385), and which have suffered the usual deschillerization and recrystallization of their augite (22383). The belt of shattering continues and some of the shattered rocks show remarkably well the results of the superinduced albitization and granulitization (22386). Acid mesostasis of a granophyric nature is often extremely abundant, and is remarkable for the large amount of apatite it may carry. The crystals of apatite are usually quite small, but in some cases may reach a length of two or three millimetres (22280, 22384).

In many of these rocks all trace of original olivine, if ever present, has been lost. Pseudomorphs, however, do occur occasionally (23594), and, as we have seen (p. 273), the mass on the western flank of Beinn na Seilg (g′) was decidedly eucritic in nature. It appears probable that in much of the gabbro-mass the olivine has been decomposed by a pneumatolytic process akin to that which operated in Central Mull,[1] and that the place of this mineral has been taken by pyroxene and iron-ore as a consequence of acidification and reheating. H.H.T.

(h) YOUNGER QUARTZ-GABBRO OF BEINN BHUIDHE

This mass is of irregular shape and varies much in rock-type. It may include more than one intrusion, as is suggested by an apparently intrusive junction that occurs within the mass as mapped, 130 yds. south of the northern summit of Beinn Bhuidhe. A coarse-grained white-weathering quartz-gabbro is there in contact with fluxion-gabbro that is apparently the margin of a dark quartz-gabbro with acid patches found along the summit of the ridge.

No contacts have been made out with the Fluxion Gabbro (i) to the north, but there is definite evidence of its relations to the Older Quartz-gabbro of Bheinn Bhuidhe (c″), and to the Eucrite (f). As the Quartz-gabbro (c″) is traced up the rocky southern slope of Beinn Bhuidhe, it becomes baked in appearance, as do also the Inner Cone-sheets by which it is cut. At the top of the hillside, where these rugged rocks give place to smooth grassy ground, on the east side of a conspicuous hollow eroded along a line of crush, the baked dark-coloured Quartz-gabbro (c″) is intruded by quartz-dolerite. The latter grades rapidly northwards into the Quartz-gabbro (h), which is nowhere cut by the Inner Cone-sheets. To the east of this contact, the Quartz-gabbro (c″)

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[1] E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 94.

is intruded, as though along joints, by hybridy-looking quartz-dolerite that is presumably connected with the Younger Quartz-gabbro (h). That the Eucrite (f) is also earlier than the Younger Quartz-gabbro is equally clear. A well-exposed contact occurs 100 yds. north-north-west of the north summit of Beinn Bhuidhe, on a steep slope above a cross-country track leading from Grigadale to Portuairk. Eucrite, baked in appearance, is there in vertical contact with quartz-dolerite which grades rapidly uphill into the Quartz-gabbro (h). The eucrite may be a screen-like mass, isolated from the main body of the Beinn nan Ord Intrusion. It exactly resembles the local variation of the Beinn nan Ord Eucrite in containing large plate-like augites, and no doubt of its identity is entertained. Quartz-gabbro, mapped as part of the Younger Quartz-gabbro, is in contact with the Eucrite (f) south of the junction of the Allt Grigadale with Grigadale Loch (Fig. 37, p. 266). At the contact the quartz-gabbro has a well-developed acid mesostasis, and the eucrite appears to be highly acidified (24434). In this neighbourhood the Eucrite is usually in a completely shattered condition (p. 267), and the fact that the quartz-gabbro alongside is quite sound suggests that the eucrite is the older rock (*see* p. 206). No boundary has been fixed between (h) and (d) but, as already mentioned (p. 251), (d) is cut by a cone-sheet referred to Centre 2, while (h) is later than these sheets. J.E.R.

Petrology.—As pointed out in the field descriptions given above, this mass is irregular in form, variable in character, and may include more than one intrusion. Such a state of affairs is certainly borne out by microscopic examination, which confirms the variability, and shows that the migration of an acid mesostasis has produced local mineralogical and structural changes that give a general hybridy appearance to the resultant rocks. In its most normal condition and where most free from acid veins and mesostasis, as at and near the summit of Beinn Bhuidhe, the rock is a moderately coarse ophitic dolerite composed of a brownish augite that ophitically encloses well-formed unzoned crystals of bytownite (21553). Olivine was apparently an original constituent, but in the majority of cases its former presence can only be inferred from ill-formed serpentinous or chloritic pseudomorphs. It is, however, clear that the most basic and least modified portions of the mass approximate to eucrite in composition. Even within the area of a thin section the presence of an acid magma makes itself evident, and it is seldom that either an augite or a plagioclase felspar is observed which does not show signs of disturbed equilibria (21554). The effect of the acid magma and emanations on the original augites is often most marked (22345), for it has brought about a cleansing of the mineral by the local destruction of the schiller-structure (Fig. 45 A, p. 320) and has been responsible for some recrystallization, sometimes as augite and at other times as rhombic pyroxene. Also, there has been a general production of minute scales of biotite within the augite of the attacked areas.

To the south of Grigadale the amount of acid material is much greater. It has not only affected radical changes in the augite and generally reduced the basicity of the felspars, but occupies ill-defined areas throughout the rock, in which it appears as an apatite-rich microcrystalline and often micrographic mixture of alkali-felspar and quartz (22389–90). Against the acid mesostasis the felspars are albitized and often fringed with orthoclase, while augite shows corrosive effects involving recrystallization and the local development of hornblende and rhombic pyroxene. The acidified felspars are peripherally charged with apatite, often continuous from the acid mesostasis, while the original basic felspars are particularly free from this mineral. It is in those portions of the mass which appear to have carried original olivine that the development of rhombic pyroxene is most pronounced (22375). It occurs associated with much modified augite enveloping talcose pseudomorphs after olivine, and from its fairly strong pleochroism appears to be hypersthene.

In the neighbourhood of Achosnich (22351) the rock is a moderately coarse ophitic dolerite without much acid mesostasis. The felspars, however, are intensely albitized (Fig. 45) in a patchy manner, and riddled with albite-veins. There is a good deal of iron-ore present which has developed biotite at its peripheries.

At the edge of the mass, to the north-west of Achosnich, where it is in contact with the Great Eucrite, it takes on the character of a fine-grained granulitic rock composed of small irregular crystals and granules of augite, somewhat stumpy prisms of much twinned clear plagioclase of very variable composition, and abundant magnetite with a little biotite developed at the expense of the iron-ore (22352). The rock has the appearance of having been in a great measure recrystallized, probably as the result of reheating effected by the intrusion of the Great Eucrite.

The gabbro occasionally encloses small strips of what seems to be older material which are more or less completely recrystallized. They are subgranulitic in texture and one of them is remarkable for its abundance of rhombic pyroxene (enstatite). This rock (22353) suggests not so much a recrystallized normal gabbro as a recrystallized hybrid. The rock forming the screen to the north-west of the summit of Beinn Bhuidhe, and referable to the Beinn nan Ord Eucrite, is a coarsely ophitic dolerite that shows abundant signs of contact metamorphism (22625). The felspars have become intensely turbid with schiller inclusions, enclose little granulitic patches of pyroxene and magnetite, and are strung with slender veins of albite. Interstices between the felspars are filled with epidote, sphene, actinolite in fibrous masses, prehnite, and quartz charged with vermicular chlorite. H.H.T.

(i) FLUXION GABBRO OF PORTUAIRK

This mass is in contact with three other intrusions, relations with which are obscure. It has been mapped as a separate intrusion, chiefly because it differs from its neighbours in rock-type. Its characteristic fluxion structure is developed almost everywhere. Biotite is a frequent constituent and is easily seen where the rock is soft and decomposed, as, for example, along a scarp bounding the fields south of Portuairk. On the coast it is well exposed and often presents the fuzzy, white-weathering appearance of a quartz-gabbro. There, numerous bands of fine-grained granulitic rock are to be seen, while to the east, next the Great Eucrite (E), vertical west-north-west joints are conspicuous. Possibly these may be contraction joints due to cooling that followed the heating up of the mass by the Great Eucrite.

An apparent contact with the Great Eucrite occurs at high-water mark, where the boundary line has been drawn on the map (p. 303). Its junction with the Eucrite (f) to the west could not be determined satisfactorily, although exposures along the coast are excellent. J.E.R.

Petrology.—Although mappable as a unit, this mass is clearly of mixed nature, and has been produced by the modification of gabbroic or eucritic material by an acid magma. As developed on the shore north of Portuairk (22373), the rock is an intensely acidified gabbro in which the old augite has been deschillerized, and locally recrystallized and charged with minute scales of biotite. In some parts of the rock the augite has been converted into uralitic hornblende and the original basic felspars albitized. The matrix in which these gabbro elements are set is rich in alkali-felspar and quartz, but also contains abundant rhombic pyroxene, now pseudomorphed by fibrous green hornblende, and a growth of plagioclase of fairly acid composition. Biotite occurs in association with the iron-ores and also as a chloritized constituent of the matrix.

To the west (21557), and a little inland from the shore (22354), the rock has a moderately coarse ophitic structure and is obviously modified. The augite is corroded and deschillerized in the usual manner with the development of scales of biotite and patches of uralitic hornblende. Further, there is a general albitization that chiefly affects the marginal portions of the basic plagioclase crystals, but also traverses them as narrow veins. The acid mesostasis, where present, consists of albite-perthite and quartz, and its local modifying influence is strongly marked. Abundant biotite, as large scales, occurs in connexion with the iron-ore, and rhombic pyroxene occasionally occupies moderately large areas.

The Great Eucrite (E) close to the margin of the Portuairk Gabbro also exhibits fluxion to some extent (22355), but its eucritic nature is practically unimpaired. It contains abundant crystals of unaltered olivine, but is perhaps rather richer than usual in rhombic pyroxene (hypersthene). The augite shows local deschillerization and there is slight albitization of the basic plagioclase.

In places the invasion of the gabbro (i) by acid material is obvious in the field, and in such extreme cases (22374) the rock appears as an acidified gabbro or basified granophyre. The augites of gabbro origin are much corroded and the original basic plagioclases have been resorbed, rendered turbid by schillerization, and fringed by a regrowth of albite-perthite which also strings through them in all directions. The acid magma has crystallized as an interstitial turbid mass of alkali-felspar and quartz, frequently showing graphic structure and charged abundantly with apatite. One of the chief pieces of evidence for the resorption of the basic plagioclase and its subsequent regrowth as a more acid variety, is furnished by the fact that the abundant apatite of the mesostasis is included in the soda-rich plagioclase that borders the more basic felspar. At the same time, albitization in its generally accepted sense, that is to say, molecular change effected by the introduction of the soda molecule in solid-solution, has also taken place to a limited extent, as is proved by the strings of soda-plagioclase which penetrate into the interiors of the basic felspars.

Certain granulitic masses (22365) enclosed by the gabbro (i) are fine-grained rocks that suggest cone-sheet or some other fine-textured intrusive rock that has been thermally altered by the surrounding mass. One such mass shows an open lattice of felspar-laths embedded in a more or less completely granulitized matrix of augite, oligoclase felspar, and magnetite, with abundant biotite. Acid veins emanating from the surrounding intrusion often string through the granulitized xenolithic masses, and by absorption of basic material have greatly modified their original composition. Near their junctions with the basic rock they have developed an abundance of green hornblende, while in the body of the veins large plates of biotite are common. For the rest, the vein is a soda-rich granophyre composed of oligoclase-albite, albite-perthite, and quartz, with, here and there, small flakes of biotite and slender needles of green hornblende. The basified rock, both in the development of hornblende and biotite, and in the abundance of perthitic alkali-felspar, assumes a likeness to the tonalites and monzonites (p. 99) which we have reason to believe are rocks of hybrid nature.

A review of the Fluxion Gabbro as a whole certainly gives the impression that we are dealing with an abnormal mass that owes its peculiarities largely to the interaction of acid magma with a basic rock already in a solid or partially solid condition. That such interaction took place in the main before the intrusion of the mass into its present position appears probable, although the further migration of acid magma has locally exaggerated the effects. H.H.T.

(j) Felsite, South of Aodann

This small mass consists of a dark-grey non-porphyritic felsite, and forms a prominent rocky hill. On its east side the felsite cuts the Aodann Quartz-gabbro (d). The latter is granulitized at the contact (22337), while 50 yds. away it is quite unaltered. The felsite in turn is cut by an inclined sheet of grey-black dolerite that is definitely chilled against it, and also by thin basic dykes. The dolerite sheet is considered by Dr. Thomas to be certainly baked (24403), as it indeed appears to be in the field. Yet there is no visible intrusion in the neighbourhood of later age than itself. It therefore seems necessary to postulate some younger intrusion below ground (*see* p. 255).

The same type of felsite as the above is found in smaller masses, usually sheet-like in form though with irregular margins. These are of frequent occurrence in the western half of the Old Gabbro (b). Farther west, they are also met with across the belt of country traversed by the Inner Cone-sheets, which they are found to cut. For example, west of the Allt Grigadale on a scarp that borders a tributary stream, and just north of the projecting arm of the Beinn nan Ord Eucrite (f) (Fig. 37, p. 266), an interesting series of events can be made out. The Garbh-dhail Quartz-gabbro (c), which is much sheared, is cut by porphyritic cone-sheets that are quite sound, and that run at right angles to the side of the scarp. Along the edge of the scarp, transgressing across the cone-sheets and chilled against them, is a dyke-like intrusion of the dark, non-porphyritic felsite. The baking of felsite of the same type as the above, which occurs in this vicinity next to the Beinn nan Ord Eucrite, has been already mentioned (p. 267). J.E.R.

Petrology.—This mass (21577) is a medium-grey splintery rock without macroscopic structures or porphyritic crystals. It is traversed by irregular narrow veins filled with greenish to white material, and contains a few scattered crystals of pyrites. Under the microscope, viewed with a low power, it appears to be a more or less normal fine-grained felsite with a few quite small phenocrysts of albite-perthite. The matrix is largely felspathic and has the appearance of having been glassy. It carries small irregular inclusions of a xenolithic nature which are rich in iron-ore and exhibit a microcrystalline structure. These xenoliths suggest some basic rock, probably basalt lava, as the felsite is in contact with such rocks on its southern margin.

A higher magnification reveals the fact that the Felsite has been intensely metamorphosed. The fine felsitic matter has been granulitized with the formation of abundant minute rounded granules of pale-green pyroxene and crystals of magnetite of similar dimensions which are scattered throughout the rock. The granules average from 0·005 mm. to 0·01 mm. In the veins and cracks the granulitic texture is somewhat more coarse and the granules reach 0·03 mm. in diameter; also, the green colour of these veins, visible in the hand-specimen, is found to be due to an abundance of a deep-green alkali-pyroxene that is strongly pleochroic in shades of green and yellow. This pyroxene is similar to that present in the Augite-diorite of Camphouse (p. 154) and in certain contaminated rocks to which it appears to be related. A further likeness is furnished by the occurrence of sphene in both cases.

The Aodann Felsite is cut by a thick basic sheet (24403), which has also shared in the metamorphism that has affected the earlier intrusion. This sheet is a quartz-dolerite of basic Talaidh type, in which contact alteration has produced a general turbidity of the felspars and a development of biotite in association with iron-ore, and in the chloritized mesostasis.

The fact that the Aodann Felsite appears to be younger than all the other intrusions with which it is in contact, apart from the dolerite sheet, makes it difficult to account for the pronounced thermal alteration those two rock-masses have suffered. It may be, as Mr. Richey has suggested, that the metamorphism is due to some later underground intrusion that does not reach present surface-levels.

Felsite similar to that of Aodann occurs as dyke-like masses farther west. A rock from a point 360 yds. east of the northern end of Loch Caorach is of this nature (24401), but it has suffered a more or less complete granulitization at the hands, probably, of the Beinn nan Ord Eucrite. The ground-mass is now a microgranulite replete with small granules of yellowish-green pyroxene and magnetite, the abundance of which suggests an intermediate composition for the original rock.

Another mass of dyke-like character which cuts the gabbro to the south-south-east of Grigadale (24430) is a fine-grained dark-grey rock with small porphyritic felspars, and glomero-porphyritic groups of felspar and augite in a microcrystalline matrix. The felspar is a moderately alkaline plagioclase (andesine to oligoclase) while that of the matrix appears to be mainly oligoclase with some albite and orthoclase. The felspathic matrix contains abundant small elongated crystals of augite intergrown with magnetite, and there is a suggestion that its original structure was akin to that of the craignurites of Mull. The rock has, however, been modified to a considerable degree by subsequent granulitization, perhaps due to the adjacent Eucrite of Beinn nan Ord. H.H.T.

CHAPTER XIX

TERTIARY RING-DYKES OF CENTRE 3, ARDNAMURCHAN

The plutonic intrusions of Centre 3, the latest centre of igneous activity in Ardnamurchan, constitute an excellent example of a ring-dyke complex. This complex is itself completely preserved, but has replaced large portions of those of earlier date.

The main features of the complex have been already described in Chaps. V and XV, but we may briefly reiterate certain differences between it and its predecessors. Explosive action that is manifested around Centre 1 by the formation of vent-agglomerates, and in the case of Centre 2 chiefly by the brecciation of ring-dykes, is here almost unknown. The only good example is afforded by the narrow Quartz-dolerite (I) of the Interior Complex, which is brecciated and injected with granophyre throughout its length. Fine-grained igneous xenoliths, for the most part cognate to the intrusion in which they occur, are abundant in the majority of the Ring-dykes of Centre 2, and are locally plentiful in the Quartz-gabbro of Faskadale (A), the outermost and probably the earliest ring-dyke of Centre 3. In the Great Eucrite (E) they are very sparse, and occur chiefly as elongate strip-like masses. It is likely that these fine-grained xenoliths denote comparatively superficial conditions of consolidation. The complex of Centre 2 certainly appears to occupy an intermediate position between the largely superficial complex of Centre 1 and the more deep-seated and mainly plutonic complex of Centre 3.

The eucrites and quartz-gabbros typical of the ring-dykes about Centre 2 are well represented in the complex of Centre 3. But in the Interior Complex of Centre 3, enclosed by the Great Eucrite, biotite becomes an almost invariable constituent mineral. In this, the last phase in the plutonic history of Ardnamurchan, a rock-series of unusual character was produced, the origin of which has been already discussed (pp. 98 and 211).

The Great Eucrite (E) and Outer Eucrite (E′) conveniently subdivide the complex for descriptive purposes, and the ring-dykes outside and partly surrounding these two Eucrites form the subject of the present chapter. They consist of the following intrusions (*see* Index Map, p. 201) :—

(A) Quartz-gabbro of Faskadale.
(B) Fluxion Gabbro of Faskadale.
(C) Gabbro of Plocaig.
(C′) Gabbro, south-east of Rudha Groulin.

Of the above intrusions, the two first-mentioned, (A) and (B), are typical arc-shaped ring-dykes, and are obviously related to Centre 3. The other two are small masses, and are included here chiefly for convenience.

(A) QUARTZ-GABBRO OF FASKADALE

This ring-dyke has been traced around almost half the circumference of the Later Complex. At its north-eastern end, it is separated from the Fluxion Gabbro, that usually accompanies it on its inner side, by a screen-like mass of agglomerate. The Quartz-gabbro and screen are in faulted contact along a gorge cut by the Allt Faskadale. On the west side of the fault, west of Faskadale Bay, the Quartz-gabbro is not seen again. At its visible termination to the south-west, east and north of Beinn na Seilg, the Quartz-gabbro disappears beneath a roof formed of rocks belonging to the Earlier Complex. Possibly it again reaches the present surface, south of Sanna Bay, as the mass called the Younger Quartz-gabbro of Beinn Bhuidhe (h), which there emerges from below an inclined roof of older rocks (p. 255).

The intrusion varies considerably in composition along this great length of outcrop. In the eastern portion, the prevalent variety is a coarse-grained gabbro, with white-weathering felspar, which differs markedly from the adjoining dark-weathering Fluxion Gabbro (B). Iron-ore is often plentiful and olivine is usually present. An acid mesostasis is sparsely developed. The rock is in fact a somewhat basic quartz-gabbro. Sometimes olivine becomes conspicuous in amount and the rock passes into eucrite, as, for example, north and south of Lochan Clach a' Chorrach south-east of Meall an Tarmachain. The change in type is here only local, and near by, south-east of the loch, typical quartz-gabbro containing drusy cavities lined with quartz is met with. Westwards of this locality the rock is a more acid type, though olivine is usually present. The pale rough-weathered surfaces characteristic of quartz-gabbro, due to a well-developed acid mesostasis, are here often seen. A variety already described from the Earlier Complex (p. 252) consisting of a mixture of two types, quartz-gabbro and brown-weathering quartz-dolerite, is found south-west of Meall an Tarmachain and north-west of the Amhainn Chrò Bheinn stream, at a point 600 yds. east-north-east of the Kilchoan–Achnaha road. Sharp contacts between these two very different rocks often occur, as though the quartz-gabbro were xenolithic, but more usually there is a gradual passage of one type into the other.

North-west of the last locality, along a ridge flanked to the west by a marked north-west hollow, a porphyritic fine-grained type is met with. A sharp intrusive junction of this rock with normal-grained quartz-gabbro occurring to the north is to be seen 250 yds. north-west of the Amhainn Chrò Bheinn. The following description of the contact in microscopic section (21586), supplied by Dr. Thomas, may be given here. 'The fine-grained rock consists of granular augite and little prisms of plagioclase enveloping phenocrysts of augite and labradorite. It becomes much more highly charged with iron-ore towards its margin. The coarser rock is a quartz-gabbro brecciated and invaded by the finer material. There appears to be some granulitization of the felspars, but the degree of metamorphism is not high.' The line of separation between these two types was mapped westwards for a short distance obliquely down into the hollow, but could be traced no farther.

On either side of the Kilchoan–Achnaha road, typical quartz-gabbro with blade-shaped crystals of augite is well exposed. Towards the outer margin, next the Hypersthene-gabbro, it grades into a finer-grained type, sometimes containing porphyritic felspar. This finer-grained facies is present also over a wide area farther west, beyond the Kilchoan–Achosnich road and towards Beinn na Seilg. There, it may also be marginal, developed in relation to a roof, since the intrusion is extending under roof immediately to the west.

Net-veining is especially abundant east of the Allt Faskadale gorge. The rock of the veins seems in the field to be an acid quartz-dolerite, rather than a granophyre. Granophyre containing biotite and veining the Outer Cone-sheet Complex just outside the gabbro is, however, to be found on the east side of Glas Bheinn (*see* pp. 288–9). Crumbling banks of quartz-gabbro alongside the Amhainn Chrò Bheinn stream, north of Glas Bheinn, contain much fine-grained quartz-dolerite, often sheet-like, which is apparently intrusive in the quartz-gabbro. Xenoliths are present in abundance right across the intrusion west of the Kilchoan–Achnaha road, and occur both as bands and as angular blocks of fine-grained basic material (22249 and 22250). They are infrequent elsewhere.

Marginal Relations.—Along its outer margin, the Faskadale Quartz-gabbro is bounded by the Outer Cone-sheet Complex of Centre 2, except to the west where it comes into contact with the Earlier Ring-dykes. J.E.R.

At its north end, on the east side of Faskadale Bay, a contact with cone-sheet rock is well seen. Quartz-gabbro of basic type is there exposed along the rocky foreshore west of Faskadale House, and is in a soft, much weathered condition, and apparently unbaked. In contrast, the adjoining cone-sheet rock that extends for several hundred yards along the coast to the north is hard and highly baked. Just north of a sandy inlet to the north of Faskadale House, contact of these two rocks is seen. The Quartz-gabbro terminates rather vaguely with fine-grained crystallization against quartz-dolerite cone-sheet rock, which it veins. A microscopic section of the junction shows that the cone-sheet is highly granulitized, while the fine-grained gabbro in contact is quite unaltered (23456). South of Faskadale Bay, east of the Allt Faskadale, the Cone-sheet Complex forms a highly baked wall that stands up as a conspicuous scarp above lower ground to the west occupied by the Quartz-gabbro. E.B.B.

Perhaps the most striking demonstration of the relative ages of the Quartz-gabbro and the Outer Cone-sheets is afforded by the ridge of Glas Bheinn, where the Quartz-gabbro margin turns westwards to cut almost at right angles across the cone-sheet belt for a distance of a mile. No actual contacts of gabbro and cone-sheets have been there observed, but both rocks are often exposed within a few feet of one another. The contrast between the highly baked cone-sheets and the soft unbaked gabbro is a sufficiently striking indication of their relative ages. For example, a massive cone-sheet extends as a conspicuous rocky feature up the southern side of Glas Bheinn at Tom a' Chrochaidh, and becomes highly baked at the summit of the ridge next to the unbaked quartz-gabbro that forms the opposite, northern slope.

West of Glas Bheinn, the Quartz-gabbro is in contact with the Hypersthene-gabbro (a) for a distance of 1¼ miles. Owing, in part at least, to discontinuity of exposure no actual junction of the two gabbros has been located. In the valley between Glas Bheinn and the Glebe Hill, the two intrusions are separated for a short distance by a narrow screen-like strip of compact amygdaloidal basalt and brown-weathering dolerite, interpreted as basalt lava cut by basic sheets. The Quartz-gabbro on the north side of the screen is chilled to brown-weathering quartz-dolerite near the contact. The Hypersthene-gabbro to the south, unlike its normal marginal facies, is coarse-textured. Just beyond the eastern end of the screen, where the two gabbros come together, their actual junction is not seen, but adjacent specimens of the gabbros were collected for microscopic examination. Of these, the Quartz-gabbro is a normal rock, while the Hypersthene-gabbro is shattered and invaded by acid material (*22371*). Farther west, on the west side of the Kilchoan-Achnaha road, exposures are fairly good, but here again the junction could not be located. Possibly shattering of the Hypersthene-gabbro at its contact with the Quartz-gabbro may be the reason for the difficulty. On either side of the belt of obscure rock, a yard or two wide, each type is definitely recognizable, the hypersthene-gabbro coarse in grain, the quartz-gabbro much finer and weathering brown.

The Quartz-gabbro is overlain by a capping of basalt lava and agglomerate on the south-west side of Meall an Tarmachain (Fig. 39, p. 286); and on the east side of Beinn na Seilg, as already stated, disappears beneath a roof. This roof is formed largely of the Quartz-gabbro (c) cut by the Inner Cone-sheets of Centre 2, and its edge is marked by a highly baked scarp that extends along the hillside. The top of the intrusion, immediately below the roof, is composed of granophyre. When traced downhill the granophyre becomes more basic and grades into an acid type of quartz-gabbro, about one-third of which is made up of acid mesostasis. Farther downhill, normal quartz-gabbro is found. This gradation downward from the acid into the basic rock is best seen along crags on the west side of a stream that flows northwards across the edge of the roof, where rock exposure is continuous. In this section there are no xenoliths or sharp contacts between rocks of different type such as would suggest separate magmatic injections. Gravitational separation of the more acid from the more basic portion of the quartz-gabbro magma would seem to have taken place (*see* p. 210). The distance along the roof for which the acid top is seen is half a mile.

A good contact of the upper, acid portion of the intrusion against roof occurs at the base of the northern spur of Beinn na Seilg which is formed of the Eucrite (f). Hybridy looking granophyre also makes contact with roof composed of the Quartz-gabbro (c), adjacent to the Old Gabbro (b), 550 yds. south of Lochan an Aodainn. North of this point, the margin of the Quartz-gabbro (A) has not been definitely located. Quartz-dolerite is seen in intrusive contact with the Old Gabbro, but whether it belongs to the Quartz-gabbro (A) or the older Quartz-gabbro (c) is not known.

Along its inner margin, the Faskadale Quartz-gabbro is bounded by the Fluxion Gabbro of Faskadale (B) for a long distance. Evidence supplied by a contact suggests that the Quartz-gabbro is the earlier (p. 289).

Beyond the western termination of the Fluxion Gabbro, on the south side of Meall an Tarmachain, the Quartz-gabbro extends beneath the capping of basalt lava and agglomerate referred to above. The base of this capping is slightly inclined south-westwards. It is separated by the valley of the Amhainn Chrò Bheinn from smaller cappings to the south which form a link between it and the outer wall of the intrusion. On the west side of the main capping the slightly inclined edge of the Quartz-gabbro is marked by an escarpment which is conspicuously jointed, and presents a columnar appearance when viewed from a distance. The joint planes are inclined northwards and are evidently approximately at right angles to the inclined base of the capping. They are to be ascribed to the heating up of the country rocks of the capping by the underlying intrusion and their subsequent contraction on cooling.

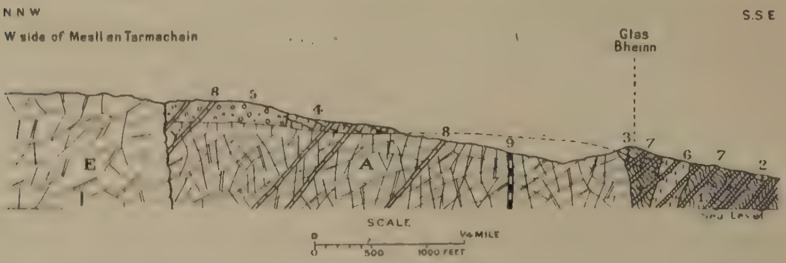

FIG. 30.—*Section from Meall an Tarmachain to Glas Bheinn, north of Kilchoan.*

1, *Moine Schists.* 2, *Trias.* 3, *Lower Lias (limestone and shale).* 4, *Tertiary basalt lavas.* 5, *Vent-agglomerate (Centre 1).* 6, *Porphyritic Dolerite of Glas Bheinn (Centre 1).* 7, *Outer Cone-sheets of Centre 2.* 8, *Cone-sheets (Centre 3).* 9, *Quartz-felsite dyke.* A, *Quartz-gabbro Ring-dyke (Centre 3).* E, *Great Eucrite Ring-dyke (Centre 3).*

West of the Meall an Tarmachain capping, the inner margin of the Quartz-gabbro (A) comes into contact with the Great Eucrite (E), which there is good reason to believe is of later date. J.E.R.

Petrology (Anal. VI; Table IV; p. 85).—As pointed out in the foregoing field descriptions, this gabbro mass exhibits considerable petrological variation when followed along its somewhat narrow outcrop. Portions are more than usually basic and assume an almost eucritic character, while at other localities more acid varieties are encountered. This variation in type, however, is merely of local significance and the bulk of the mass may be regarded as a quartz-gabbro with more or less normal characters. It is quite conceivable that the mass is multiple in origin, for, in addition to somewhat rapid changes in type, chilled junctions between coarse and fine-grained rocks are occasionally met with within the mass itself.

The gabbro, as represented by the analysed specimen (22827), is a moderately fine-grained grey rock of speckled aspect, containing a variable amount of free silica. It is composed of a greenish-brown subophitic augite, somewhat platy zoned crystals of labradorite, fairly abundant magnetite, and a little interstitial quartz and alkali-felspar. Generally speaking, the interstitial matter carries abundant apatite and has reacted to some extent upon the adjoining felspars. It will be seen from the analysis that its composition is typical of the quartz-gabbros, while its relatively low percentages of alumina and lime as well as of magnesia are features correlatable respectively with a non-porphyritic habit and a general paucity of olivine.

Many parts of the gabbro mass are of this type (21585), but occasionally a rhombic pyroxene (hypersthene) makes its appearance (21588), and the augite may adopt a diallagic structure. Sub-granulitic varieties of gabbro are also represented (21494). A good deal of the mass shows evidence of the migration of an acid magma, or magmatic residuum, which has modified the original structure. Augite crystals exhibit ragged outlines (22826) and a patchiness accompanied by the separation of minute scales of biotite due to attack. Albitization of the basic felspars is more pronounced, and the interstitial quartz and alkali-felspar residue more prolific (24402). The acidification of the mass is well marked beneath the roof that covers the gabbro to the north-east of Beinn na Seilg, and there appears to have been a concentration of acid partial magma in the upper and marginal portions. Here, the rocks are of paler tint than usual and contain a copious matrix of apatite-charged micrographic alkali-felspar and quartz. The original augite shows corrosion, and the crystals of basic plagioclase exhibit résorption followed by regrowth with a more soda-rich variety (24443–4). Where the acid material has segregated immediately below the roof it is best described as augite-granophyre (24441). Except for a few kernels, these rocks contain little felspar more basic than oligoclase, but alkali-felspar in micrographic intergrowth with quartz is prevalent throughout. The augite where completely recrystallized is a greenish variety that builds granules and elongated slender prisms. Hornblende is occasionally developed at the expense of the incompletely resorbed augite of gabbro origin (24442).

Mention of contiguous rock-types that exhibit chilled margins within the mass has already been made (p. 283). Frequently, the older of the two gabbros has been crushed before the later doleritic rock has chilled against it. Such features are exhibited by the gabbro and quartz-dolerite on the south-west of Meall an Tarmachain. The older rock has been reduced to a crush-mosaic and shows slight thermal metamorphism due, presumably, to the later intrusion with which it is in contact. The dolerite at its edge is a microporphyritic rock with small porphyritic crystals of labradorite and augite in a fine-textured matrix of plagioclase laths, granular augite, and abundant magnetite (21586). Similar sharp contacts, some of a welded character, are encountered elsewhere in the main mass, close to or at its inner margin, next to the Great Eucrite, to the west of Meall an Tarmachain (24414–6, 24451). Sometimes a marked fluxion structure has developed in the doleritic rock there met with, and hypersthene has formed as a reaction product against the older gabbroic portion of the mass (24411).

The Faskadale Gabbro shows minor variations; some parts are doleritic (24397, 22366), other parts are of fine-textured quartz-dolerites (22367) that are occasionally reminiscent of the Talaidh and Ben Hiant types.

Some of the fine-grained granulitic masses enclosed in the normal gabbro may be described as granulitic gabbros. They are often veined by granophyre and have developed a rhombic pyroxene at their junction with the acid strings (22249). Such granulitic masses are obviously of an older basic rock that has undergone some modification and recrystallization (22250). A small mass of pyroxene-granulite, however, at the eastern end of the gabbro, three quarters of a mile north-north-west of Kilchoan, is a completely granulitized, originally porphyritic, rock that recalls some of the granulitized basic lavas frequently encountered within or against many of the intrusive masses (21244–5).

The capping of agglomerates and basalt lavas which occurs to the south-west of Meall an Tarmachain has been considerably metamorphosed both by the Faskadale gabbro and later intrusive masses. The olivine-basalts show recrystallization and granulitization (21852) which are more pronounced in those rocks with the finer texture. In extreme cases, the whole of the original augite has recrystallized as granulitic aggregates or as minute granules dispersed throughout the rock (21853). Coarse and more felspathic types of lava show the effects of metamorphism chiefly in the groundmass, although the felspar phenocrysts show alteration in the development of a uniform turbidity that is akin to schillerization (21854).

The country rock just outside the gabbro on its eastern side, consisting mainly of agglomerate and lavas cut by cone-sheets, is often in an intensely altered condition. Vesicular fine-grained basalts have been transformed into minutely granular masses of augite, biotite, and partly recrystallized felspar (26102). Further, these granulitized rocks are strung by granophyre that has reacted with and absorbed basic material, whereby its original composition and mineral content have been modified. The granophyre where least contaminated, east of Glas Bheinn (26673), consists of alkali-felspar, often perthitic, albite-oligoclase, and interstitial granophyric matter. In addition, there are present large plates of biotite which, it is inferred, result from the absorption of basic material. Patches of granulitized basic rocks, probably cone-sheets, may be detected in all stages of dissolution.

Where the interaction of granophyre and basic rock can best be studied it is seen that the most important change in both participants is the copious development of biotite (26672). This change is often accompanied in the granulitized rocks by the separation of rhombic pyroxene.

Definite hybrids of moderately coarse texture, in which biotite and dark-green hornblende play prominent parts, are frequently produced as extreme cases of basification of the invading acid magma (26095, 26674). The likeness of such rocks to some of those of monzonitic affinities met with elsewhere in Ardnamurchan (p. 340) strengthens the conviction that these latter are not normal differentiates, but owe their distinctive characters to the basification of an acid magma.

The basalt and agglomerate screen to the west of Faskadale will be dealt with later (p. 317). The rocks are much altered, and the basic porphyritic lavas have been completely recrystallized to a fine granular mass of pyroxene, biotite, plagioclase, and iron-ore, while felspar phenocrysts have recrystallized as a mosaic. Deformation during metamorphism has developed in some instances what may almost be described as a schistose structure, there being a definitely parallel orientation of the recrystallized minerals and a pulling out of the felspar mosaics that represent the original porphyritic crystals (21850).

(B) Fluxion Gabbro of Faskadale

Fluxion gabbro as a rock-type is often met with in Ardnamurchan. In the present instance, as in all others, biotite is a usual constituent, and in microscopic slices Dr. Thomas has frequently found hypersthene (p. 278).

The inclination of the fluxion planes is often towards Centre 3, at rather low angles (20 to 40 degrees). There is no direct evidence of the shape of the intrusion, for it and the Quartz-gabbro on its outer side occupy a low-lying belt of country between a baked rim of country rock and the more durable Eucrites (E) and (E′).

On account of its distinctive rock-type, the Fluxion Gabbro (B) proved relatively easy to separate in the field from the adjacent ring-dykes just mentioned. Actual junctions between these intrusions are, however, difficult to locate, chiefly because exposures are discontinuous. The evidence afforded by contacts noted, coupled with the fact that all three intrusions are different in rock-type, justifies our regarding them as separate injections.

The only contact observed with the Quartz-gabbro of Faskadale occurs in the bank of a tributary stream east of the Allt Faskadale, 800 yds. W. 25° N. of the summit of Beinn an Leathaid. The Quartz-gabbro is a coarse-grained rock, white on weathered surfaces, solid at the contact but soft and weathered a few inches away. The Fluxion Gabbro is weathered down into a kind of sand and contains biotite flakes: the inclination of its fluxion-planes is here at a high angle. Under the microscope the apparently contact-hardened quartz-gabbro is found to be unaltered mineralogically, except that it is strongly albitized (22663).

Contact with the Outer Eucrite can best be seen in the north bank of the Allt Rath a' Bheulain (not named on Memoir-map), east of Meall nan Con. Along this stream a good section across the whole breadth of the Fluxion Gabbro is exposed. Its more central portion is coarsely crystallized, but fluxion structure and darker colour everywhere distinguish it from the white-weathering Quartz-gabbro outside it. Exposures fail, however, where these two masses come into contact. Upstream towards the Outer Eucrite, fluxion structure becomes more obvious and the rock is finer grained. At the actual junction, the fineness of grain is very marked, but the Eucrite in contact also has marginal characters, and so no deduction as to relative ages is possible. The marginal type of the Eucrite is that commonly found, in which iron-ore is developed to the partial or complete exclusion of olivine, and the rock takes on the appearance of a quartz-gabbro with a slight development of acid mesostasis. Farther upstream, between the inner side of the Eucrite and the granulitized rocks of the Meall nan Con screen, a small mass of fluxion gabbro is found, and resembles the mass downstream in being intruded by similar fine-textured sheets. Again, 1100 yds. south-south-west of this point, another small mass of fluxion gabbro occurs in a similar position at the inner margin of the Outer Eucrite.

At its northern extremity the Fluxion Gabbro could not be separated satisfactorily from the Great Eucrite (E), since the Eucrite also has a fluxioned margin, and rock is discontinuously exposed. Again, at its southern extremity, the Fluxion Gabbro is exceedingly difficult to separate in badly exposed ground from the Quartz-gabbro (A), and the mapping is largely arbitrary.

Fine-grained sheets are found traversing the Fluxion Gabbro, but do not bear marked chilled edges. They have been noted chiefly in the Allt Rath a' Bheulain, south-west of Beinn an Leathaid, and are restricted to the outcrop of the Fluxion Gabbro. In microscopic section, according to Dr. Thomas, they are midway in composition between quartz-dolerite and tonalite (22654). They are probably consanguinous with the Fluxion Gabbro, both being characterized by containing biotite. J.E.R.

Petrology.—The Fluxion Gabbro of Faskadale, from microscopic evidence, appears to be an abnormal mass composed in the main of hybrid rocks produced by the action of a granophyre-magma upon a eucrite. All stages of acidification can be studied. As already pointed out (p. 289), the main features that distinguish this mass from those in which it is in contact are its fluxion structure and the general presence of biotite. Amongst the specimens collected are eucrites that show but little acidification, and these consist of olivine, ophitic brownish augite, and basic labradorite or bytownite felspars in moderately large much-twinned crystals (22648).

Acidification, possibly in conjunction with reheating, has produced, in the initial stages, hypersthene at the expense of olivine; and biotite, sometimes in large flakes, at the expense of augite and iron-ore; while there is a marked disturbance of equilibrium in the felspar crystals (22653). In addition, there are rocks rich in iron-ore (22697), and others which are almost entirely felspathic (22698), or composed of felspar and olivine (22701). The structure of the majority of the specimens suggests that we are dealing with a moderately coarse gabbroid rock that has been broken up and invaded by acid magma. Evidence of hybridization is furnished by large old basic felspars that are much fissured (*22699*), albitized, and resorbed; and by schillered augites that have been resorbed and locally deschillerized. These xenocrysts lie scattered or closely packed in an acid finer textured matrix that consists of smallish crystals of acid plagioclase, alkali felspar, and quartz, the last two minerals often in graphic intergrowth (*22664*). The matrix also contains large crystals of apatite (*22650*). The resorption of the gabbro xenocrystal material has modified the invading acid magma and has allowed the separation of a pale, almost colourless augite that fringes the original pyroxene and also occurs as isolated hypidiomorphic crystals. Biotite has also been developed in varying amounts (*22649*), more particularly in those areas which were rich in original iron ore. In the extreme cases of assimilation by the acid magma and its consequent basification, as observed in acid veins and minor intrusive masses fine-textured rocks have resulted which must be referred to as hybrids. These masses are holocrystalline and only betray their hybrid nature by the presence of relatively few incompletely digested crystals of diallagic augite and basic plagioclase of gabbro origin. The bulk of such rocks, apart from xenocrysts, consists of small crystals of oligoclase-andesine felspar, quartz, perthite, biotite, and abundant recrystallized pale-green to colourless augite with a little iron-ore. The acid plagioclase occurs as stumpy crystals, while the perthitic orthoclase, which is usually turbid, occurs either as separate crystals or is intergrown with quartz (*22654*).

There is little doubt that this fluxion gabbro has been injected in a semi-fluid condition. Such a condition is not only indicated by the fluxion banding but by the microscopic evidence of abundant xenocrystal material carried by an acid and fluid base. Such intimate commingling of eucritic and granophyric types, and the attendant far-reaching absorptive processes that have operated within the mass, suggest that the original eucrite was either not completely solidified or was still at an elevated temperature when it was invaded by acid magma, and that it was carried forward as a somewhat heterogeneous gabbro mass into its present position.

The resorption phenomena are interesting from a petrogenetic standpoint as indicating the tonalitic and monzonitic facies assumed by hybrids of this nature. H.H.T.

(C) GABBRO OF PLOCAIG

This small, elongate mass extends for a short distance in ill-exposed ground between the outer, northern margin of the Great Eucrite (E) and the Hypersthene-gabbro (*a*), and appears to be a distinct intrusion from both its neighbours. In the hand specimen, it is finer grained and darker looking than the Eucrite, but is not very different in composition. It contains olivine and sometimes porphyritic felspar.

No contact with the Hypersthene-gabbro has been found, but 300 yds. east of Plocaig, west of a stone dyke where exposures are fairly good, the outer part of the Gabbro (C) contains xenoliths that exactly resemble the Hypersthene-gabbro. The xenolith sliced (24425) shows, however, but little sign of contact alteration. South and east of this point, next to the Great Eucrite, the rocks are granulitized. If these outcrops are rightly mapped as part of the Plocaig Gabbro, they indicate that this mass is separate from and earlier than the Great Eucrite. J.E.R.

Petrology.—As developed at Plocaig (21502), the rock is a moderately coarse olivine-gabbro that contains abundant fresh olivine, an ophitic brownish augite, and a twinned and zoned basic labradorite-felspar with practically no accessory minerals. It involves some interesting granulitic masses rich in hypersthene, and also includes xenolithic masses of the Hypersthene-gabbro of Centre 2 (24425). The xenoliths of gabbro, except for the development of a little uralitic hornblende, appear to have suffered slight alteration. The hypersthene-bearing granulite (24424) contains some remarkable intergrowths of magnetite and rhombic pyroxene, the magnetite assuming a dendroid form. Such intergrowths appear to result from the reaction of olivine with an aluminous melt, for they are frequently noticed in the Hypersthene-gabbro and Great Eucrite (Fig. 42, p. 305) to occur as a zone separating olivine from augite and basic plagioclase. H.H.T.

(C′) GABBRO SOUTH-EAST OF RUDHA GROULIN

This small mass (lettered eD on Memoir-map) is designated quartz-gabbro on field-determination. The only specimen sliced is, however, an olivine-hypersthene-gabbro (22635). In form, it appears to be a sheet. Along a scarp around its northern end a base to the intrusion is seen which is inclined gently to the south and cuts the Outer Cone-sheet Complex of Centre 2.

Along its inner, southern side next to the Great Eucrite, the gabbro (C′) is evidently baked, and xenoliths, apparently of it, were noted in the margin of the Great Eucrite (E). Presumably, therefore, it is a portion of some larger mass that has been in part replaced by the Great Eucrite. Since it is later than the Outer Cone-sheets of Centre 2, it is included with the ring-dykes of Centre 3 in the present chapter.

A special interest attaches to this mass. Along its north-east side, coarse pegmatitic veins proceed from its base and traverse granulitized cone-sheet rock. These veins are largely composed of pyroxene, but contain layers and spots of felspar together with green epidote, honey-yellow sphene, and long brown needles of apatite. The latter minerals are large enough to be easily distinguished in the hand-specimen. On its north-west side, the gabbro is found at its actual contact with the cone-sheet rock to grade rapidly into a marginal skin of dolerite, and no pegmatite veins are seen. J.E.R.

Petrology.—The main mass of this gabbro is a moderately coarse-grained olivine-hypersthene-gabbro of eucritic composition (22635), in many respects similar to the Hypersthene-gabbro of Centre 2. The olivine is a fresh iron-magnesian variety, and forms small rounded crystals that occur either isolated or as glomero-porphyritic groups embedded in large crystals of bytownite. The augite is coarsely ophitic and is associated with what iron-ore the rock contains. The rhombic pyroxene, which is not a highly pleochroic variety, is also ophitic towards the felspar but has been pseudomorphed to a great extent by fibrous green hornblende.

A development of biotite as scales within the augite and in the ferriferous pseudomorphs after olivine, as also the production of actinolitic hornblende, suggest some reheating of the mass and slight thermal alteration, probably at the hands of the Great Eucrite (E).

One of the most interesting features connected with this mass is the passage, as veins, of alkaline residual matter from the consolidating gabbro into the neighbouring cone-sheet complex. The alkaline magma has hybridized with the cone-sheet material, forming rocks rich in alkaline felspars and pyroxenes, and of strikingly abnormal composition. Similar hybrid types have been produced in the cone-sheet complex by alkaline emanations from the Great Eucrite (p. 311, 22274). Their nature and likeness to the augite-diorite hybrids of Camphouse have already been discussed (p. 155). H.H.T.

CHAPTER XX

TERTIARY RING DYKES OF CENTRE 3, ARDNAMURCHAN (*continued*)

THE intrusions to be described in this chapter are as follows (*see* Index Map, p. 201) :—

- (D) Porphyritic Gabbro of Meall nan Con screen.
- (E) Great Eucrite.
- (E′) Outer Eucrite.
- (F) Quartz-gabbro of Meall an Tarmachain summit.
- (F′) Quartz-gabbro, south side of Meall an Tarmachain.

The Porphyritic Gabbro (D) forms the southern part of the Meall nan Con screen, which separates the Outer Eucrite (E′) from the Great Eucrite (E). It is evidently earlier than the two Eucrites, along the contact with which it is obviously baked except at its south end, where its separation from the Eucrites becomes a difficult matter. South of Meall nan Con, the Quartz-gabbro of Meall an Tarmachain (F) intervenes intrusively between the two Eucrites. Where the Eucrites come together, north and south of the Meall nan Con screen, it was not found possible to locate their actual contact, although there are indications north of Meall nan Con of the later age of the Great Eucrite. Since it is a feature of both intrusions that they are practically unchilled at their contacts with older rock-masses, it is not surprising to find that their mutual junction cannot be exactly determined.

(D) PORPHYRITIC GABBRO OF MEALL NAN CON SCREEN

The southern portion of the Meall nan Con ridge, which is formed of granulitized agglomerate, is flanked to west and east by arm-like masses of fine-textured gabbro with felspar phenocrysts. These arms are apparently connected with a fairly large mass of coarser-grained porphyritic gabbro that occupies lower ground immediately south of the ridge. The arms are highly contact altered adjacent to the Outer Eucrite (E′) and the Great Eucrite (E), and are consequently easy to separate in the field from these intrusions. The contact alteration becomes less marked in the main mass of the Porphyritic Gabbro. At its southern extremity, the gabbro is coarser in texture and less apparently porphyritic. It is consequently very difficult there to distinguish it from the Eucrites, as already mentioned.

This marked decrease southwards in the contact metamorphism of the Porphyritic Gabbro is a remarkable feature. Possibly those parts of the intrusion next to the much older agglomerates of Meall nan Con had in consequence become colder, and so were more readily metamorphosed than parts farther away. The metamorphism will be dealt with in detail later together with that of other portions of the Meall nan Con screen (p. 315).

(E) GREAT EUCRITE

This massive ring-dyke has been already frequently referred to. On the Memoir-map it will be seen that it forms a complete ring encircling a complex of other intrusions (the Interior Complex). As compared with the intrusions within and outside it, the Eucrite is highly resistant to weathering. Numerous crush-lines directed north to north-west cross the intrusion, and their positions are marked by hollows of erosion. Except for such discontinuities, the Eucrite forms a complete ring-ridge that surrounds a central area of low relief occupied by the Interior Complex. A striking sectional view of this great rock-wall is obtained from the Kilchoan–Achnaha road, which follows a deeply cut erosion-hollow between the towering purplish-tinted mass of Creag an Airgid to the east, and Beinn na h'Imeilte to the west. Little vegetation grows upon these rocky hills, which remain much as the ice-sheet left them, with conspicuous *roches moutonées* on which striæ are frequently preserved. The road a little farther north emerges from this rocky defile into the broad, low-lying central area. At this point, the inner side of the eucrite wall extends to left and right as two curving lines of high crags that can be followed with the eye around to the north where they rejoin one another and so complete the circle (*see* Pl. VI, p. 321, for view from north-east).

The typical rock may be described as a coarse felspathic gabbroid rock containing both augite and olivine; but the proportion in which these two ferromagnesian constituents occur varies greatly, and often abruptly. Where olivine becomes abundant and augite subsidiary, the rock may be termed an allivalite. The crystals of olivine are always conspicuous in size. Indeed, in some places this mineral forms crystal-aggregates a foot long, as for instance about 500 yds. south-west of the summit of Meall nan Con. The augite frequently occurs as large plates that ophitically enclose the felspar.

A local variation in type only noted at a high level along the south-eastern portion of the Beinn na h'Imeilte ridge may be mentioned. There, about 900 yds. east-south-east of the summit, the rock becomes finer grained and contains plentiful iron-ore, having some resemblance to the quartz-gabbroid marginal portion of the intrusion (p. 201). Xenolithic material is often abundant in this vicinity. Possibly we may be here approaching a local top to the mass. Towards the outside of the intrusion, east of Creag an Airgid, a pale or white variety closely allied to quartz-gabbro (22686) is intermingled with the dark normal eucrite in small patches and in streaky fashion.

Pale, felspathic eucrite may be seen at almost any point along the ring-dyke, often in irregular areas, but frequently forming broad bands. There is no difference in texture between the pale areas and the normal darker rock, but their mutual margins are usually well defined. As a rule, the pale bands are aligned more or less parallel to the course of the ring-dyke. Their elongate form is presumably due to flow-movement, perhaps at a late stage in the intrusion of the magma, since the bands are broad in relation to their length.

True flow banding is fairly frequent along the inner side of the south-eastern portion of the intrusion, though of rare occurrence elsewhere. The bands are usually inclined at an angle of 45 degrees, in some places inwards towards Centre 3, in others outwards from it.

An internal feature of special interest are pegmatite veins. These are met with around the whole intrusion, and are best developed in its exterior portions. They are usually rich in augite, sometimes to such a degree that the vein-rock may be termed pyroxenite. They are sometimes composite. For example, a thick vein east-north-east of Meall an Fhir-eòin consists of augite-rich marginal portions and a felspathic centre, 2 inches and 8 inches wide respectively. The normal augite-rich veins are usually much narrower than this, but among them are numbers of straight-running individuals as much as 2 or 3 inches across. In direction these relatively wide veins are everywhere parallel to the course of the ring-dyke. Further, they are either vertical or else highly inclined. Augite-rich pegmatite similar to that forming the veins is often found in irregular masses of considerable size enclosed in the normal eucrite, and continuity between such masses and pegmatite veins has sometimes been observed. For example, on the ridge half a mile north of Meall Meadhoin, and just south of the south end of a quartz-dolerite intrusion lettered gD on the Memoir-map, a pegmatite vein inclined at 80 degrees towards Centre 3 widens out rapidly at its north-west end into a mass of pegmatite. The pegmatite masses must represent residual liquid portions of the intrusion in which fluxes had become concentrated, which may have acted as reservoirs from which the cracks that developed in the cooling and contracting mass were filled.

Though the longitudinal pegmatite veins are the most striking, others can be recognized, thinner and less regular, which run mainly at right angles to the direction of the Ring-dyke. Good examples of such cross-veining may be seen along the top of the Eucrite ridge one third of a mile north of Meall Meadhoin, directed towards the Achnaha Centre (3). They are usually steeply inclined or vertical. The two sets of pegmatite veins, aligned as they are with reference to the Achnaha Centre and to the course of their parent ring-dyke, appear to provide convincing internal evidence of the steep nature of this intrusion. The longitudinal veins are so persistently vertical, or nearly so, that it seems impossible not to conclude that the walls of the intrusion are correspondingly steep.

Two easily accessible localities at which to examine the longitudinal veins may be mentioned. The first is along the walls of a west-north-west cleft, a short distance north of the new road from Achnaha to Sanna, on the Sanna side of the Eucrite ridge. The veins there seen deviate little from the vertical, excepting one that is inclined north-west at 60 degrees. The other locality lies east of a loch (Lochan an Dobhrain) a mile north of Glendrian farm, where there are fine examples of the longitudinal veins, spaced a few yards apart. The absence of pegmatite veins from the inner half of the Eucrite can be demonstrated in this vicinity, south of the loch above mentioned.

The longitudinal pegmatite veins may frequently be seen to traverse the broad bands and patches of pale eucrite already described. In some cases the direction of the bands and the veins practically coincides, as, for example, on the western slopes of the Eucrite ridge about two-thirds of a mile north-north-east of Achosnich. More usually there is a small divergence of direction between them. For instance, east of the Kilchoan-Achnaha road, about 600 yds. south-west of Creag an Airgid summit, elongate masses of the pale eucrite are directed N. 30° E., while the pegmatite veins traversing them run E. 10° to 20° N.

MARGINAL RELATIONS

The marginal relations of the Great Eucrite are of special importance in Ardnamurchan geology, on account of this intrusion being in contact with so many different rock masses. Evidence that the Eucrite is older than the Interior Complex of Ring-dykes which it encloses will be discussed in the next chapter. Along the greater part of its outer margin, it is considered to be intruding the various rocks that border it. While age relations are in some cases easily determined, in others much difficulty is experienced, for, notwithstanding the unchilled nature of the Eucrite at its outer margin, it has frequently effected little contact alteration of earlier gabbros. The relations of the outer margin in regard to each of these rock-bodies are described below, beginning with the Meall nan Con screen and proceeding in a clockwise direction round to the Cone-sheet Complex west of Faskadale Bay.

Meall nan Con Screen. Basalt lavas, agglomerates, tuffs, and intrusions all form part of this screen, and have been already briefly described under their respective headings. A character common to all is their intensely baked condition, amounting in many places to complete granulitization. This makes the diagnosis of the rocks in the field often a matter of great difficulty, more especially the distinction of basalt lavas from fine-grained tuffs. Large felspars that occur in the tuffs of the south part of the screen give these rocks a pseudo-porphyritic appearance. At first sight they might be mistaken for the adjoining, highly baked porphyritic gabbro (D), but a closer scrutiny discloses their heterogeneous, fragmental nature. Brown-weathering dolerite in broad outcrops is associated with the grey-weathering tuffs, and probably represents cone-sheets. Such rocks are to be seen 600 yds. south of the summit of Meall nan Con, but owing to the masking of their original character by granulitization their mapping could not be carried out. The highly altered condition of these Meall nan Con rocks emphasizes the pre-Eucrite nature of the mass as a whole. It is an easy matter to trace the line of junction of the baked rocks, that form a conspicuous ridge, with the Great Eucrite to the west, and with the

Outer Eucrite to the east. To north and south the screen extends downhill sufficiently far to show that the junction is steep, and the granulitized rocks truly screen-like.

On Fig. 40, the ridge along the sky-line to the left is formed by the northern part of the screen; the dotted line indicates the junction of screen with Great Eucrite, which occupies the remainder of the view; the abrupt hill-face on the extreme right of the sky-line is the upper part of the great scarp that surrounds the Interior Complex and marks the inner side of the Great Eucrite. In this view, from screen to scarp, we therefore see practically the whole width of the Great Eucrite Ring-dyke.

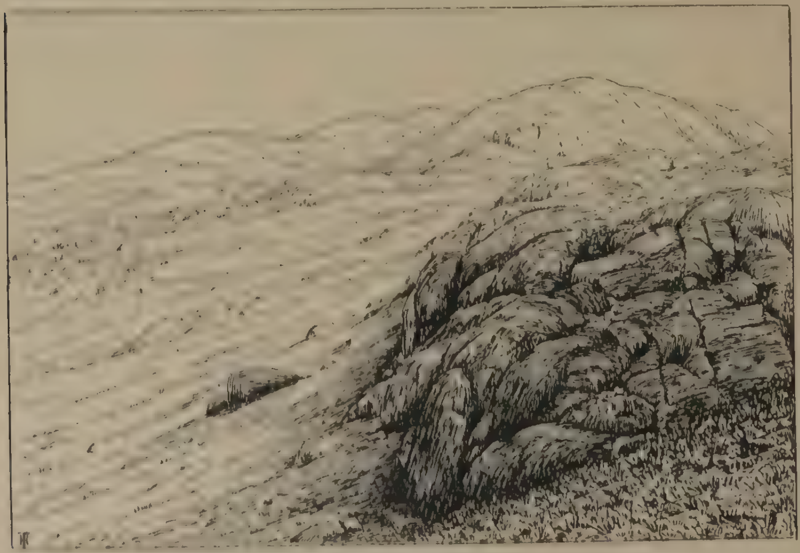

FIG. 40.—*View of Meall nan Con and Meall Meadhoin from north. Dotted line indicates junction of Meall nan Con Screen, forming ridge to left, with Great Eucrite Ring-dyke, forming Meall Meadhoin and foreground.*

Drawn from Geological Survey Photograph No. C. 2818.

Immediately north of the screen, the Great Eucrite comes into contact with the Outer Eucrite. At this point there is some evidence of an intrusive relationship between the two Eucrites. Acid net-veins are found throughout the rocks composing the screen, and are especially abundant next to the two Eucrite intrusions on either side, though never plentiful in the Eucrites themselves. North of the screen, however, extending downhill from its termination, a line can be drawn between what is taken to be the margin of the Great Eucrite with a little acid veining and a gabbroid rock of somewhat different appearance in which net-veins are profuse, and which is mapped with the Outer Eucrite. The change in character is abrupt along this line, but no intrusive contact could be located between the two Eucrites. It is perhaps an impossible task to find a junction between two such coarse-textured and essentially similar rocks, but without such direct evidence it cannot be definitely said that they are different injections, likely though this may be.

At some junctions between Great Eucrite and screen the only change in the former at the actual contact is a slight decrease in coarseness of grain. Such a contact may be seen on the north side of Meall nan Con, 460 yds. north-north-west of the summit. A finer-grained margin is found farther south, east of a small loch on a watershed between two streams that flow respectively north and south parallel to the west side of the screen (Fig. 41). At this place the junction is best exposed. The rock-scarp that elsewhere closely marks the contact of the granulitized rocks with the eucrite, here includes a portion of the Eucrite itself. On the rocky upper part of the scarp, above the level of the talus and towards the left of Fig. 41, a vertical junction between the Eucrite and screen is well seen. The Eucrite becomes distinctly finer in texture a few yards from the contact, at which it still is, however, fairly coarse in texture. The Eucrite of the crag overlooking the loch is crossed by a set of vertical joints that run at right angles to its junction with the screen. This junction extends from the left, where it crosses the scarp as described, somewhat oblique to the line of the scarp. It is consequently situated only a few yards back from the cross-jointed eucrite of the crag. The vertical joints are presumably

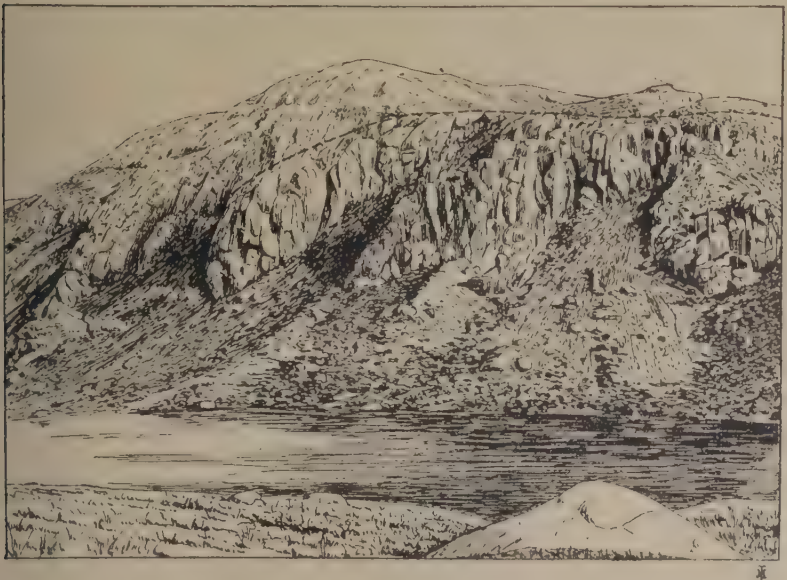

FIG. 41.—*View of crags on west side of Meall nan Con.*

Broken line indicates junction of granulitized rocks of Meall nan Con Screen with Great Eucrite Ring-dyke, that forms vertically-jointed crag overlooking loch.

Drawn from Geological Survey Photograph No. C. 2817.

due to contraction that accompanied cooling. They have not been filled either by gabbro-pegmatite or by acid magma such as forms net-veins, and would therefore appear to be of somewhat late formation. In the interior of the Great Eucrite similar late contraction-joints are also developed, but are not specially noticeable at close quarters, since they are rather widely spaced. They are, however, a remarkable feature of the ring of crags that mark the inner side of this great ring-dyke as viewed from the centre of the Interior Complex. What appear at this distance as closely-spaced vertical joints crossing the crags are everywhere directed towards this central view-point. On the steep face of Beinn na h'Imeilte the joints are especially well displayed. They may be compared with the cross-joints commonly met with in ordinary basic dykes, and afford a further indication of the steep-sided form of the Great Eucrite Ring-dyke.

From the watershed at the small loch, the junction between Eucrite and screen continues southwards, keeping at first a straight course downhill along the base of the marginal scarp. It then must deviate from this course and passes around a highly granulitized little mass on lower ground below the scarp. This projecting tongue of the screen is the most highly altered portion of it. The interior of the tongue, which shows less alteration than the margins, consists of porphyritic fine-grained gabbro. This gabbro, as shown by frequent outcrops, is in continuity with the less altered porphyritic gabbro (D), already described (p. 294), which forms the southern part of the screen. Traced towards the margins of the tongue, the much altered porphyritic gabbro becomes finally a banded granulite at the actual contact with the Eucrite, which is unchilled. Transitional stages are found between the banded granulite and the porphyritic granulitized gabbro, a conclusion confirmed by microscopic examination of material collected (p. 316). At the junction with the Eucrite, layers of coarse rock resembling eucrite alternate with the finer-grained banded granulite, as though eucrite magma had been injected simultaneously with the flow-movement of a plastic mass. A similar interbanding is found at one other point along the outer margin of the Great Eucrite, at a contact with the Hypersthene-gabbro (a) (p. 303).

As already mentioned (p. 294), the separation of the porphyritic gabbro of the screen at its south end from the Great Eucrite and Outer Eucrite proved difficult, and the exact limits of the screen in this direction could not be accurately fixed. It is certain, however, that the screen ends in the low ground separating Meall nan Con from Meall an Tarmachain, and that the Great Eucrite and Outer Eucrite there come together again. At this point the Outer Eucrite appears to be more prone to vary in composition than the Great Eucrite, but it has not been found possible to locate any intrusive contact between them.

Meall an Tarmachain Screen.—This screen forms a conspicuous ridge that bounds the central peak of Meall an Tarmachain to the north-west, and overlooks lower ground to the north occupied by the Great Eucrite. It forms a definite outer limit to the Great

Eucrite at this locality, and separates it from an intrusion of quartz-gabbro (F) that constitutes the central peak of Meall an Tarmachain. Its rocks are greatly contact altered, but are perhaps chiefly agglomerate, as is shown by their frequently observed heterogeneous nature. The north-east end of the screen, as mapped, is partly at least composed of quartz-dolerite (p. 320). The relations between this baked quartz-dolerite and the Quartz-gabbro (F) could not be decided in the field. It is not impossible for this quartz-dolerite to be the margin of the Quartz-gabbro (F), baked by the Great Eucrite. At another point, however, quartz-gabbro included with (F) is intrusive against eucrite that appears to be continuous with (E) (*see* p. 318).

At the south-western end of the screen, above a little loch that lies in a hollow in the Great Eucrite, the margin of the latter turns abruptly eastwards across the direction of the screen. It then comes against quartz-gabbro included with (F), as above referred to.

Meall an Tarmachain Capping.—This capping overlies the Quartz-gabbro of Faskadale (A). Along the short distance that the Great Eucrite is in contact with it, their junction is steep or vertical. This junction is marked by a hollow eroded in the margin of the Eucrite, which extends straight down a steep hillside. The marginal rock, though coarse in grain, is more acid than the normal eucrite, since it contains a certain amount of acid mesostasis and also iron-ore, while olivine is somewhat scarce. It is in fact a basic type of quartz-gabbro. Acid net-veining is especially profuse in the granulitized rocks of the capping immediately next to the Eucrite, and probably emanated from this acid marginal portion of the intrusion.

Quartz-gabbro of Faskadale (A).—The fact that the Great Eucrite cuts across the Meall an Tarmachain capping that overlies the Quartz-gabbro (A), suggests that the Eucrite is the later of these two intrusions (Fig. 39). There is also some direct evidence of their relative ages westwards of Meall an Tarmachain along the 1½ miles that they are in contact. A narrow zone of fine-grained gabbro, sometimes highly baked, is met with at intervals along this contact as far west as the Kilchoan–Achosnich road, and is intruded by the Eucrite. This zone satisfactorily fixes the outer limit of the Eucrite. On the other hand, its relation to the Quartz-gabbro outside it remains obscure. In some places it is abruptly succeeded by the Quartz-gabbro, as though distinct from it. In others, a gradation from one rock into the other appears to take place. Since a high degree of baking is only locally met with, it seems improbable that this zone is a screen older than both the intrusions which it separates. It seems more likely that it is a remnant of an early injection that preceded the main intrusion of the Great Eucrite.

This marginal rock is a brown-weathering fine-grained gabbro, often with porphyritic felspar, which on fractured surfaces has a peculiar dark-green colour that seems to mark some degree of contact alteration. Under the microscope, as investigated by Dr. Thomas, it is sometimes obviously granulitized (22687). In other cases, though extremely hard, as if baked, there are no signs of mineralogical change (22366, 22367). The rock is an olivine-bearing fine-grained quartz-gabbro or quartz-dolerite.

In a knoll on the east side of the Kilchoan–Achnaha road, the marginal rock, a porphyritic fine-grained gabbro (22366), is traversed by veins of quartz-gabbro which might have been derived from the marginal part of the Eucrite or from the Quartz-gabbro (A). Farther west, 400 yds. east-south-east of Lochan na Crannig, north-east of the Kilchoan–Achosnich road, a similar porphyritic rock is clearly intruded by the Great Eucrite. This exposure is situated just south of a north-north-west basic dyke shown on the map as cutting the Great Eucrite. At the contact, the Eucrite resembles a coarse-textured quartz-gabbro and sends veins into the porphyritic rock. In this neighbourhood the porphyritic gabbro ends somewhat abruptly on its outer side against fluxion gabbro, which is here, apparently, a marginal portion of the Quartz-gabbro (A), but no contacts were located.

At a higher level than the exposures described above, immediately below the Meall an Tarmachain capping, the only direct evidence of the prior age of the Quartz-gabbro (A) is forthcoming. Here the Quartz-gabbro comes directly into contact with the Great Eucrite. It is found to be clearly altered, its weathered surfaces having that grey-black hue characteristic of baked rocks. Under the microscope, it resembles closely in rock-type another specimen collected from the Quartz-gabbro in this vicinity (21587), but is found to be crossed by lines of crushing; its felspars are turbid, and it is certainly baked (21597). This evidence appears finally to decide the relative ages of the Quartz-gabbro and Great Eucrite. It is, however, difficult to understand why similar contact alteration is not met with along the margin of the Quartz-gabbro across the valley to the west. Possibly the Quartz-gabbro retained too much of its original heat, except close to the capping, to be appreciably affected by the Eucrite. Such an explanation has been already offered in another case (*see* p. 294).

The Great Eucrite west of Meall an Tarmachain exhibits the same quartz-gabbroid marginal variation as it does next to the capping. Adjoining the Kilchoan–Achnaha road, this marginal type passes gradually into the normal eucrite in a distance of about 50 yds.

South-west of Loch na Crannaig, the Kilchoan–Achosnich road runs along the base of a high scarp that is composed of fine-grained quartz-gabbro, often porphyritic, baked in appearance and profusely net-veined. It was not found possible to separate this rock from the main portion of the Quartz-gabbro (A) to the south-east, to which it most probably belongs. The junction with the Great Eucrite must lie near or at the base of this scarp.

Quartz-gabbro of Aodann (d).—A narrow belt of quartz-gabbro separates the Great Eucrite from the Old Gabbro (b), and connects the area of the Quartz-gabbro (A), as mapped, with that of the Aodann Quartz-gabbro (d). Its significance is not known. It is separated from the Old Gabbro (b) by a strip of granulitized porphyritic rock that microscopically resembles cone-sheet types (21562).

Farther north-west, a junction is exposed between coarse-textured eucrite and the fine-grained porphyritic variety of the Aodann Quartz-gabbro. This junction is situated about 80 yds. south-west of the Achosnich road, 550 yds. east of Aodann. The margin of the Quartz-gabbro here forms a rocky feature that extends somewhat obliquely along the hill-slope, below which eucrite is frequently exposed. At the contact located, only a small outcrop of eucrite is seen, but it suffices to show that the junction is inclined at 70 degrees to the south-west, outwards from the Achnaha Centre (3). The Quartz-gabbro at the contact has that dark-green hue on fractured surfaces already noted in the case of the fine gabbro that separates the Quartz-gabbro (A) from the Great Eucrite (p. 301). Under the microscope, it is found to be granulitized (22333), while specimens collected a few yards away show no signs of contact alteration (22334, 22323).

From this point north-westwards to Achosnich, no satisfactory evidence of age relations could be obtained. But alongside the northmost house in this village, the marginal type of the Eucrite, containing iron-ore, is found to invade and enclose as xenoliths a fine-grained quartz-gabbro with porphyritic felspar. There is no doubt whatever about the intrusive character of the Eucrite, but owing to discontinuity of exposure the relationship between the porphyritic rock and the normal coarse-textured type of the Quartz-gabbro (d), exposed a few yards away, cannot be determined. Possibly the porphyritic rock may be an early injection of the Great Eucrite, as already suggested for the similar marginal porphyritic gabbro found west of Meall an Tarmachain (p. 301).

Younger Quartz-gabbro of Beinn Bhuidhe (h).—West of the track to Portuairk, 700 yds. north-west of Achosnich, a slight ridge of fine-grained non-porphyritic gabbro, extremely hard and baked in aspect (22352), separates the Great Eucrite from the Quartz-gabbro (h). The question arises here again as to whether the fine-grained rock is a screen, or a much altered margin of the Quartz-gabbro, or an early injection of the Eucrite. Coarse-textured eucrite occurs in sharp contact with it, and whatever may be its origin, it appears to be earlier than the Great Eucrite.

Fluxion Gabbro of Portuairk (i).—An apparent contact between this intrusion and the Eucrite occurs along the shore, at which the Fluxion Gabbro (22374) would seem to be the earlier intrusion, but there is no marked contact alteration. The issue is further complicated by the fact that the outer portion of the Great Eucrite, eastwards of this place, is itself a fluxion rock (22355).

Hypersthene-gabbro (a).—Towards the neck of a promontory on the north-east side of Sanna Bay, formed of the Hypersthene-gabbro, this rock is highly contact altered and finally becomes a banded granulite. Exposures of eucrite are seen a few yards away, belonging to the Great Eucrite, which is evidently responsible for the alteration. The banded granulites are traversed by gabbroid veins.

East-north-east of Plocaig, where the outer margin of the Hypersthene-gabbro turns southwards and is cut across by the outer edge of the Great Eucrite, the Hypersthene-gabbro together with the Cone-sheet Complex in contact is highly baked.

Outer Cone-sheet Complex of Centre 2, west of Faskadale.—The intense contact alteration affecting these rocks marks them as older than the Eucrite alongside. Alteration is evident even as far north as the coast. If it is all due to the Great Eucrite, it shows how greatly such pre-ring-dyke rocks are affected as compared with the Quartz-gabbro Ring-dykes that bound the Eucrite to the south. For the highly altered rocks west of Faskadale, though largely fine-grained and therefore easily affected, include also the Quartz-gabbro of Centre 1 (p. 145).

The margin of the Eucrite against these baked rocks may be seen, for example, 1000 yds. west of Faskadale Bay. At this point the Eucrite has its customary marginal facies of quartz-gabbro with conspicuous iron-ore, and becomes finer in texture at its extreme outer margin (24013), a few yards north of a track that runs to the north of a small loch (Lochan Dubh). The margin is traversed by thick veins of granophyre, poor in ferromagnesian minerals but containing abundant dark xenolithic patches. Similar broad acid veins, as well as numerous fine veins, cut the granulitized older rocks including cone-sheets. The fine veins are somewhat dark in colour and apparently baked. Possibly, therefore, the rocks outside the Great Eucrite have been affected by more than one intrusive episode subsequent to the injection of the Outer Set of Cone-sheets of Centre 2. J.E.R.

PETROLOGY OF THE GREAT EUCRITE

(Anal. III, Table IV, p. 85)

The Great Eucrite of Centre 3, both petrographically and scenically, is one of the most important rock-bodies of Ardnamurchan. Like most of the other gabbros, it shows considerable variation both in structure and composition, and these variations have been already discussed in the foregoing account of the field relations. It has been pointed out that we may encounter felspathic masses approaching anorthosite in character, olivine-rich bodies of considerable dimensions, and other masses in which iron-ore appears to have segregated to a greater extent than elsewhere. Further, it has been suggested that this heterogeneity, in part at least, is due to movement within a partially differentiated mass.

In its most typical development the eucrite is a grey moderately coarse-grained gabbroid rock, in which dark ferromagnesian constituents and a greasy-lustred felspar occur in approximately equal proportions. The average grain-size is from a quarter to half an inch, but the felspars occasionally attain larger dimensions and show well-developed twin-lamellation in the hand-specimen. On a weathered surface olivine is frequently rendered conspicuous by the separation of limonitic decomposition products.

The rock consists of olivine, augite, a basic plagioclase felspar, and, usually quite subordinate, iron-ore, while hypersthene is an occasional constituent. The three main components occur in variable proportions, and this variation, coupled with changes in the basicity of the plagioclase, leads to the production of allivalitic and anorthositic types on the one hand, and normal olivine-gabbros on the other.

In the usual eucritic type the olivine occurs as irregularly bounded grains that may be an eighth of an inch in greatest dimensions (22675) and are clearly of early separation. They seldom, if ever, show crystal-outline, but are usually rounded and embayed as if partially resorbed. The mineral is generally in a fresh condition and is almost colourless in thin section, but when decomposed there is a fairly copious separation of magnetite and the pseudomorphs are composed mainly of magnetite and talc (21510); ordinary serpentinous decomposition products are, however, frequently met with. It has a moderately wide axial angle and optically positive sign which take it out of the fayalite group, and which are features characteristic of those magnesian olivines which are somewhat rich in iron. Such a composition is confirmed by the general character of the pseudomorphs. The augite, black in the hand-specimen and pale-brown with a tinge of green in thin section (21508), appears to be the normal aluminous variety that is common to all the gabbro masses. Usually it is definitely ophitic (21251), and frequently encloses completely crystals and grains of both olivine and felspar. It is commonly free from minor inclusions, but occasionally presents brown margins towards plagioclase and frequently has well-developed schillerization. It is invariably of later solidification than either olivine or felspar.

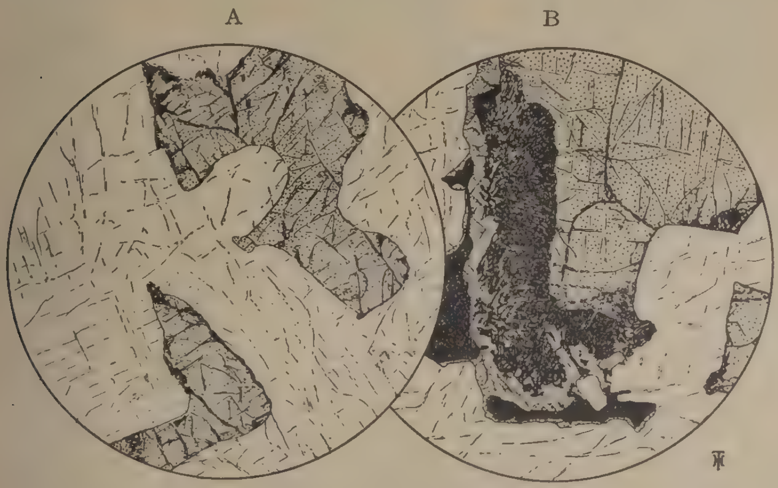

FIG. 42.—*Great Eucrite.*

A. (22675)×20. *Eucrite, typical of the Great Eucrite of Centre 3. The section shows olivine with slight marginal development of secondary magnetite, and plagioclase that varies in composition from basic labradorite to bytownite.*

B. (22355)×20. *Same type with well-developed reaction border between olivine and felspar. The reaction border consists of dendroid magnetite and hypersthene.*

The basic plagioclase in the normal eucrite varies from a basic labradorite to bytownite. It is usually zoned and much twinned, and occurs as mutually interfering somewhat elongated crystals. Where in contact with augite, however, or when completely enveloped by this mineral, it has had an opportunity of developing idiomorphic outlines. Frequently all the felspar has an optically negative sign, indicating the bytownite-anorthite end of the plagioclase series, but in other varieties of the rock the optical sign is variable, showing that, in such, labradorite-bytownite is the dominant species (22675). The latter felspar has a mean refractive index of about 1·57, corresponding to a composition of approximately Ab_3An_7. Felspar commenced to crystallize from the magma at a very early stage, for small globular crystals of a basic plagioclase are occasionally completely enclosed by olivine (22364). The bulk of the felspar, however, is moulded upon olivine and is, at any rate as far as its external zones are concerned, of later consolidation than this mineral.

Hypersthene occurs usually, in subordinate amount, in close association with olivine. It often forms what appears to be a reaction zone between olivine and felspar. At other times it occurs bordering olivine or occupying the place of this mineral in intimate association with magnetite (22364, 21507). Occasionally the zone of rhombic pyroxene on the margin of olivine is followed outwards by a zone of augite which separates the rhombic pyroxene from felspar (22355). In the cases of kelyphitic borders to the olivine, magnetite is concentrated at the olivine margin and extends in dendroid or graphic manner throughout the hypersthene (Fig. 42 B), demonstrating that the rhombic pyroxene is a reaction product of a siliceous melt and the iron-magnesian olivine.

Accessory minerals are rare in the eucrite. Iron-ore is sparingly represented except along the outer margin and in certain segregations; apatite is almost universally absent except in the acid veins and gabbro-pegmatites described below (p. 308). The presence of apatite can usually be explained by the intervention of a partial magma in which this mineral was concentrated concurrently with magmatic volatile constituents.

Quite frequently a diminution in the proportion of augite in the eucrite gives rise to rocks of allivalitic nature. They are texturally similar to the eucrite and contain an identical olivine, but the plagioclase is generally more basic and less obviously zoned (22629).

By the increase of felspar at the expense of both olivine and augite the eucrite becomes anorthositic (21511) and of paler colour than the normal rock. Anorthositic bands and patches are quite common (p. 295) and consist mainly of bytownite with subordinate olivine and augite.

Amongst the more felspathic types occurring along the outer margin, or as segregations in the interior (22319, 22686), may be mentioned moderately coarse ophitic rocks that are more or less devoid of olivine and consist of somewhat elongated interlocking crystals of basic labradorite and ophitic brownish schillerized augite with a little iron-ore in large irregular crystals. The felspars commonly show slight albitization by an acid mesostasis, and the augite may exhibit local deschillerization with the generation of small scales of biotite in the affected portion.

Such slight acidification of the eucrite must be regarded as an effect produced by its own acid residuum. For instance, near its junction with the Quartz-gabbro of Aodann (p. 303), the eucrite is a normal, coarse-grained, olivine-rich variety with fresh olivine and a greenish diallagic augite (22325). The action of the migrating acid mesostasis has been to attack and albitize the earlier-formed felspars, deschillerize the original augite with regrowth following resorption, and to produce a residuum of alkali-felspar and quartz. In the hand-specimen this is noticeable as a veining of the solid rock by threads and streaks of lighter colour and finer texture.

Alongside the road between Aodann and Achosnich there has been a certain amount of shattering of the mass at or near its outer margin, and bands of the rock have been reduced to a comminuted condition (22322). The rock has suffered some acidification with attendant deschillerization and recrystallization of augite, decomposition of olivine, and albitization of original felspars.

It has already been mentioned that hypersthene is sometimes a constituent of the eucrite and appears as a reaction zone surrounding olivine. Hypersthene is also characteristic of the outer margin of the intrusion, south of Sanna Bay, where the rocks show fluxion structure and have a mixed aspect; and although some of these hypersthene-bearing rocks have a normal appearance (22361), it is fairly certain that the rhombic pyroxene may be regarded as a product of reaction (22323). In cases where the eucrite has been highly acidified the changes are most marked (22363). Hypersthene has been developed in large plates, and the place of the normal monoclinic pyroxene is taken by recrystallized augite of paler tint and hypidiomorphic habit. Original felspars are albitized and zoned with acid plagioclase. Biotite has developed in large and small flakes in association with both augite and iron-ores, and perthitic alkali-felspar and quartz appear as a residuum. The rock under such conditions has lost most of its original characters and offers a distinct likeness to certain of the presumed hybrid rocks described below in connexion with the later intrusions of Centre 3 (p. 332).

Pegmatite Veins.—The Eucrite is frequently traversed by veins of pegmatitic nature (p. 296). Sometimes these are merely a coarsely crystalline variety of eucrite, containing the usual essential minerals, and at other times they are of special mineral constitution and show clearly the influence of an acid residual partial magma. The ordinary pegmatitic eucrite consists of a coarsely crystalline mass of olivine, augite, and basic plagioclase with a little iron-ore (21583, 22626). The olivine may show reaction borders of hypersthene when against felspar, with the usual separation of magnetite in dendroid form. Augite may be deschillerized with the formation of scales of biotite in the affected areas, the basic felspar may be albitized, and interstices filled with dark-green hornblende. Occasionally a brown hornblende may be present, occurring in and replacing augite in the vicinity of olivine.

Sometimes hypersthene is an important constituent of the pegmatites (21545) and occurs in large ophitic crystals that are often pseudomorphed by fibrous hornblende. The felspar in such cases is less basic than that of the normal eucrite, being an acid labradorite or andesine. Other coarse types (21592) appear to have suffered considerable changes since their consolidation, for the normal augite is occasionally replaced by fibrous actinolitic hornblende and the felspar by a mosaic of prehnite.

The more purely pyroxenic veins (21499) that are quite common throughout the Eucrite are found to consist almost entirely of augite with quite subordinate felspar. The augite is a pleochroic variety, the colour varying from pale bluish-green to pale yellowish-brown in thin section. The habit is hypidiomorphic, with good crystal-faces developed towards felspar. The felspar occurs interstitially, is well crystallized, not strongly zoned, and more calcic than normal labradorite. The augite in its colour and pleochroism is similar to that of certain hybrids and is quite distinct from that of the normal eucrite.

In most of these veins and patches there has been a segregation of apatite, which often occurs as large crystals.

Granulitic and Xenolithic Masses within the Great Eucrite.—The granulitic and xenolithic masses enclosed by the Great Eucrite are sparsely distributed, mainly along the outer margin of the mass, and are represented in the collections by specimens from the neighbourhood of Aodann, Achosnich, and Sanna. These rocks form a most interesting and instructive suite, for they give some indication of the nature of early consolidations of the eucrite-magma, and also present structures that are due to reheating and attempted assimilation. As a general rule it may be stated that most of the granulitic inclusions are more basic, that is to say, richer in ferromagnesian constitutents than the normal eucrite that surrounds them. One of such rocks, collected near Aodann (22330), is a very fine-textured olivine-bearing granulite. It consists of abundant round granules of fresh colourless olivine 0·1 mm. in diameter, subordinate brownish augite, also in small granules but occasionally making larger patches by the grouping of hypidiomorphic crystals, a little iron-ore or opaque spinellid in octahedra, and a base of later-formed zoned crystals of basic labradorite felspar. There is little doubt that this rock is a granulitized representative of some early basic phase of a eucrite magma.

Other strips of granulitic material appear to be remnants of quartz-dolerite cone-sheets (22344), which by metamorphism have developed biotite and rhombic pyroxene.

An unusual type of rock has been encountered towards the western margin of the mass and appears to be a gabbro-granophyre hybrid (21526, 22356). The collected examples are fine-textured, compact rocks that are often banded, contain free quartz and alkali-felspar, and in their basic portions have the structure of a quartz-dolerite. The occasional presence, however, of large patches of diallagic augite (22356) and labradorite felspar suggests that an already solid gabbro had played a part in their formation. The rock as now constituted is made up of pseudomorphs after prismatic rhombic pyroxene, iron-ore, biotite, recrystallized hypidiomorphic augite, and a plexus of fluxionally arranged narrow twinned crystals of labradorite. Locally there are veins or patches of alkali-felspar and quartz, in which green hornblende takes the place of the more usual ferromagnesian constituents. Biotite, also, may occur in sponge-like plates, and rhombic pyroxene as ophitic patches (21526). It is possible that these rocks may be recrystallized and otherwise modified members of the suite of porphyritic cone-sheets, but I rather favour the view that they are enclosed masses of gabbro-granophyre hybrid probably belonging to the Earlier Ring-dyke Complex.

A somewhat remarkable rock occurs as a lenticle near the junction of the Eucrite with the Quartz-gabbro, just north of Aodann (22321). It consists of felspars of about an eighth of an inch in size, set in a granulitic matrix. The felspars are a basic labradorite that often shows evidence of resorption and subsequent regrowth. In the marginal portions of the felspar crystals, and extending into the matrix between them, occur abundant small globules and rounded crystals of olivine, about 0·2 mm. in diameter. The matrix is composed of small mutually interfering crystals of felspar, or of an ophitic intergrowth of felspar and augite. Similar olivine-granulites were noted near the margin of the Ben Buie Eucrite in Mull,[1] and are clearly due to the reheating and partial recrystallization of an early-formed basic portion of the eucrite. Such an origin appears to be probable in this case. The actual contact between the eucrite and granulite, though sharp, is welded, and as there has been no development of a fresh suite of minerals at the contact it is probable that the two rocks had approximately the same composition.

A very beautiful olivine-augite-magnetite-granulite has been collected from a point 750 yds. south-west of the summit of Meall nan Con (22658), while coarser rocks with similar structure and porphyritic regrown felspars are occasionally encountered along the outer margin of the Eucrite west of Meall an Tarmachain (22366, p. 302).

Metamorphism by the Great Eucrite.—The metamorphic effects of the Great Eucrite, as might be expected, were general and widespread. It has wrought definite changes in most of the other igneous rocks with which it is in contact, but perhaps the most marked effects have been produced in the Lias shales and cone-sheets, which form its northern boundary to the east of Rudha Groulin, and in the complex that forms the screen of Meall nan Con (p. 312).

As in the case of the Liassic sediments (Pabba Shales) metamorphosed by the Hypersthene-gabbro (a) of Centre 2 (p. 235), these same shales, where in contact with the Great Eucrite, have suffered an identical type of metamorphism and have been converted into an interesting series of biotite-hypersthene-hornfelses (22621–2,

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[1] H. H. Thomas *in* 'Tertiary Mull Memoir,' 1924, p. 252.

22637, 22439). They are well banded and sometimes contorted rocks characterized by a crystallization of labradorite-andesine felspar in minute stumpy crystals, patches of spongy pleochroic hypersthene, red-brown biotite, magnetite, and minute rectangular crystals of cordierite, in an alkali-felspar base that is moderately rich in apatite. The biotite usually occurs in ragged plates of spongy character, enclosing felspar. The hypersthene is an intensely pleochroic variety, and commonly forms moderately large ophitic or poecilitic patches, but occasionally occurs as minute prisms. The cordierite is frequently pinitized, but the undecomposed mineral with characteristic sectorial twinning can sometimes be detected.

The nature of the original sediments and the mineralogical characters assumed by them on metamorphism have been discussed in connexion with the metamorphism effected by the Hypersthene-gabbro (p. 235).

Certain fine-grained granulitic rocks (22637) occur between the cone-sheets west of Meall Eigin-aig and south-east of Rudha Groulin, just north of the Great Eucrite boundary. Their granulitic structure is imparted to them by granulitic augite, plagioclase, and iron-ore, which occur in a hornfelsed base of alkali-felspar and quartz. The augite is a greenish-brown pleochroic variety and occurs in greater abundance in some bands than in others that are more felspathic. The base often has free quartz around which spread lakes of quartz and orthoclase in very fine micrographic intergrowth. The exact nature of the rocks from which this metamorphic type originated is in doubt, but an original kataclastic structure is suggested, and it is possible that they belong to the agglomeratic series that occurs within the same area to the west of Faskadale.

Acid Veins in and around the Great Eucrite.—Acid veins (22305) that appear to emanate from the Eucrite, and occasionally penetrate older rocks beyond its margin, are generally of granophyric composition. They are, however, usually basified and contain remnants of undigested augite and nuclei of albitized basic plagioclase of gabbro-derivation. More or less complete assimilation of xenolithic ferromagnesian material has brought about the crystallization of biotite, and the rocks in their most homogeneous condition may be described as biotite-bearing basic granophyres. Biotite and zoned plagioclase felspar occur in a matrix of alkali-felspar and quartz, which commonly shows micrographic structure. Such veins may be observed to cut the old gabbro that forms the northern end of the Meall nan Con screen.

Certain thin acid minor intrusions that traverse the Eucrite may be referred to here, because it is more than possible that they belong to the eucrite-magma. They are likewise usually of granophyric nature and are composed essentially of acid plagioclase, alkali-felspar, and quartz. Their graphic structure is frequently quite coarse, as in the case of a dyke at the southern extremity of Sanna Bay (22360), and an excess of quartz appears as fair-sized individual crystals with a tendency towards idiomorphism in another dyke, north of Achosnich (21519). In all cases they are basified by the partial resorption of either gabbro-material or their own composite basic margins. In the latter case, basic patches in the granophyre show a fine subvariolitic structure similar to that of many of the quickly cooled quartz-dolerite or tholeiite dykes. Reaction with included basic material has usually given rise either to biotite (22359) or to hornblende that may occur as long acicular crystals replacing augite (22360).

A remarkable rock (22274), occurring just south of the mouth of Allt Sanna, is a basic granulitic hybrid formed by the hybridizing influence of acid veins emanating from the Great Eucrite on a basic granulitic gabbro belonging to the Hypersthene-gabbro intrusion (a) of Centre 2. It varies in texture from a moderately coarse highly felspathic rock with little augite, first into a band composed almost entirely of augite, and then into a typical augite-felspar-granulite containing about equal proportions of these two minerals.

The augite is a deeply coloured olive-green variety, strongly pleochroic in shades of green and brownish-yellow, subophitic to hypidiomorphic in habit. In the basic band, crystals are equidimensional and reach a millimetre or so in size. They are associated with small crystals of labradorite, large patches of pink pleochroic sphene, and some epidote. In the coarse felspathic portion, the felspars show signs of disruption and acidification, and there has been a concentration of apatite in moderately large prisms close to the basic band and also within the adjacent augite. In character and mode of origin the rock recalls the Camphouse Augite-diorite (p. 153) and certain modified rocks occurring near the outer margin of the Hypersthene-gabbro (p. 228). H.H.T.

(E′) Outer Eucrite

Typical olivine-rich eucrite forms a large part of this mass, At its northern end, alongside a stream that runs north-north-west along its outcrop, biotite is a common constituent. Acid veining is frequent here as well as farther to the south-east. Near the head of this stream, quartz-dolerite containing porphyritic felspar and biotite (22651), is veined with granophyre, and is perhaps a continuation of similarly veined dolerite that cuts across the Great Eucrite north of the Meall nan Con screen. These veined rocks resemble in composition a ring-dyke (I) of the Interior Complex, from which they may be an irregular offshoot.

A variety frequently met with east of Meall an Tarmachain, at the southern end of the mass, consists of a coarse network of felspathic eucrite, with meshes of normal eucrite. The felspathic eucrite contains augite, but not olivine (21599). South of Meall an Tarmachain a considerable outcrop of this felspathic type is met with (21851).

The relations of the Outer Eucrite to the Great Eucrite have been already discussed (p. 298). It has been shown that the Outer Eucrite is distinct from the Fluxion Gabbro of Faskadale, and perhaps of later age (p. 290). That it must be later than the granulitized agglomerates and basalt lavas of the Meall nan Con screen is evident, but some details concerning the intrusions belonging to the screen may be given here. The grey-black gabbro cutting obliquely across the screen at its north end is certainly baked throughout, and its porphyritic margin against basalt to the north is granulitized (p. 315). The Porphyritic Gabbro (D) alongside the Outer Eucrite is very highly baked, though, as already mentioned (p. 300), at the extreme southern end of the screen the alteration of the Porphyritic Gabbro appears much less intense. J.E.R.

Petrology.—The Outer Eucrite is petrologically similar to the Great Eucrite. Normally it is an olivine-rich rock, sometimes allivalitic with olivine and bytownite in about equal proportions. The olivine and basic plagioclase are not far separated from each other as regards the time of their crystallization, for they frequently exhibit mutual interference, and although felspar for the most part appears to follow olivine a basic plagioclase was sometimes the first mineral to crystallize. This early felspar phase is clearly enveloped by olivine, which in turn had a later plagioclase moulded upon it (22655). As in the case of the Great Eucrite, hypersthene in variable amount occurs in close association with olivine which it obviously replaces, and, when a zone of hypersthene separates olivine from felspar, it is to be noted that the felspar in the immediate neighbourhood exhibits signs of acidification. Other parts of the mass are more definitely augitic and consist of much twinned labradorite, a little olivine, and a variable amount of ophitic augite. When ophitic augite is predominant it frequently shows deep-brown borders towards the felspar, as was noted in the case of the Great Eucrite. Sometimes the rock is highly felspathic, with comparatively little augite and olivine (21599, 22459).

This Eucrite has suffered the same type of local acidification by its own residual partial magma as has the outer margin of the Great Eucrite. Where acid material has permeated it the felspars are albitized and zoned with less basic varieties, augite is deschillerized and fringed with hornblende (22652), and biotite has apparently been formed as a product of crystallization following resorption of augite.

THE MEALL NAN CON SCREEN

PETROLOGY

The chief interest attaching to the rocks that form the Meall nan Con screen lies in their relative antiquity and the metamorphism that has been impressed upon them by the later intrusions on either side, namely, by the Great and Outer Eucrites. The screen is of a composite nature and comprises basalt lavas, agglomerates, and cone-sheets, most of which are reduced to the state of granulites; and old gabbro intrusions that plainly show modification and the effects of thermal metamorphism. From north to south, the screen is composed of basalt lavas at the extreme northerly end, then the old gabbro of Meall nan Con (Centre 1), followed by basalt lavas, agglomerates, and cone-sheets, and at the extreme south a moderately large mass of porphyritic gabbro (D).

The Basalt Lavas.—The basalt lavas have suffered changes of an identical kind to those exhibited by the basalts which came within the metamorphic influence of the Hypersthene-gabbro (a) of Centre 2, to the north of Kilchoan, and south of Beinn na Seilg (p. 237). Their porphyritic and amygdaloidal structures are still discernible in the hand-specimens, but the rocks have a cleaner and more finely crystalline appearance and tougher texture than their unaltered representatives. The outcrop within the screen includes both porphyritic and non-porphyritic types, both of which have invariably passed over into granulites. In the porphyritic lavas that are perhaps most prevalent, the porphyritic felspars have suffered little change except slight albitization and a ragged marginal regrowth. The fine-grained matrix, however, has been more or less completely recrystallized into a finely granular aggregate of augite, hypersthene, plagioclase-felspar, and magnetite, with frequent plates of biotite which embrace all the other constituents. The rhombic pyroxene often tends to segregate on or near the larger felspars (22298), and in the more felspathic areas (22302). It builds minute rounded granules of similar dimensions to those of the augite, but is easily distinguishable by its pronounced pleochroism and manner of decomposition.

The non-porphyritic types (22307) are extremely compact rocks, now converted into the finest granulitic aggregates of augite, hypersthene, medium labradorite and magnetite, with a few scattered, small, ragged phenocrysts of labradorite. Hypersthene occurs throughout the rock, but more particularly in the felspathic areas and as granular bands of considerable linear extent. It is difficult to account for such hypersthene-rich bands without assuming actual fusion as part of the metamorphic process. Similar compact types are encountered in the agglomerates (*q.v.*) of Meall nan Con summit. In one of these (22304) occur narrow bands, composed entirely of granulitic augite, which are similar in all but composition to those of hypersthene mentioned above. The main body of the granulite may contain some olivine, probably recrystallized from the original olivine of the basalt.

The Agglomerates.—On account of the highly metamorphosed condition of the screen it is not at all easy to be certain of the rock-types originally present amongst the agglomeratic material, but it would appear that the usual trachytic or bostonitic and basaltic types formed the greater number of fragments. The acid fragments (22308) show small regrown crystals of perthite in a granular matrix of acid plagioclase, orthoclase, and quartz, while scattered through the rock as a whole are minute well-formed prisms of greenish augite and equally small grains of magnetite. These rocks compare quite closely with the metamorphosed trachytic fragments encountered in the agglomerates of the Ben Hiant vent (p. 134). The basalt lava fragments are mainly of the microporphyritic type and, like the lavas of the main outcrop described above, show small porphyritic felspars that have been reheated, albitized, and regrown, in a fine granulitic matrix of augite, hypersthene, labradorite, and magnetite, with occasional plates of biotite (22300). Quite often these fine-textured pyroxene-granulites exhibit a definite fluxion structure, but whether such is determined by the original flow-banding of the lava or superimposed as the result of reheating under stress cannot be determined, although the general coarseness of the texture would lend probability to the latter view. One such rock (21513) is composed of a coarse granular mass of hypersthene, augite, plagioclase, and magnetite, in which a well-marked banding is developed, and which envelops the usual albitized and regrown porphyritic crystals of labradorite. The grain-size, however, is greater than that usually met with in the granulitized base of the basalt lavas that form the main mass.

Within the screen, especially in that portion occupied by agglomerate, occur a number of other granulitic types which point to an acidification of the basic rocks, probably basalt lava, either before or during metamorphism.

There is plenty of evidence that the material of the screen was invaded from time to time by granophyric matter that emanated from later intrusions. The result of this invasion has been the formation of granulites, richer in the acid plagioclases and alkali-felspar, which carry biotite and hornblende as characteristic minerals. Microporphyritic basalts have usually been completely granulitized, but where traversed by acid strings, and in quartzo-felspathic areas, the rocks have developed large plates of deep-brown biotite and aggregates of recrystallized alkali-felspar and quartz (21593). Larger granophyric veins have developed biotite by the process of basification (22299). In other cases, in which completely granulitized basalt can be seen in contact with acid material, the acid magma has been basified. On crystallization it has yielded large crystals of rhombic pyroxene, now pseudomorphed, andesine to labradorite felspar in stumpy prisms, recrystallized augite, and green uralitic hornblende, in a base of quartz (21595). Biotite may occur in addition.

Cone-sheets cutting the screen, especially within the agglomerate-region, have likewise come within the metamorphosing influence of the Eucrites. They have suffered a good deal of recrystallization with the formation of hornblende and biotite, but their original structure in a great measure is preserved (22651).

Old Gabbro of Meall nan Con (*see* p. 145).—This mass is a moderately coarse-textured olivine-gabbro (21514) that consisted originally of large crystals of olivine, interlocking crystals of basic labradorite, ophitic augite, and small patches of indefinitely shaped magnetite. It has suffered to a great extent from the general thermal metamorphism that has affected all the rocks of the Meall nan Con screen. The olivine is now pseudomorphed by a highly birefringent and pleochroic green micaceous mineral charged with magnetite. The felspars, in addition to showing the effects of early shattering, are blotchy owing to local acidification and subsequent reheating. The original felspar exhibits a peculiar type of turbidity and a grey tint by transmitted light, which is characteristic of rocks that have suffered a general reheating. The turbidity is due presumably to the formation of innumerable ultra-microscopic inclusions.[1] A further result of reheating has been the formation of a narrow reaction rim of hypersthene to the olivine, which separates it from the adjoining felspars. The augite has a well-marked schiller structure that appears to have been induced as a secondary feature, and occasionally it has a narrow fringe of amphibole separating it from the more siliceous parts of the rock.

Acidification is noticeable in the felspars, which have their exteriors resorbed and replaced by oligoclase; also, this mineral makes irregular clear patches within the older turbid labradorite. Small patches of micrographic orthoclase and quartz, rich in apatite, occur interstitially, and augite where in contact with this material has reacted with the formation of biotite. The acidified areas often have a microgranulitic structure determined by the recrystallization of pyroxene and felspar. This structure suggests that the rock continued to be under metamorphic influence, or was subjected to fresh metamorphosing conditions, after the acidification had been accomplished. This is also borne out by the appearance of the felspars which show much more pronounced modification by solid solution than is usual in simple cases of acidification.

Farther to the north the gabbro passes more or less insensibly into what must have been a quartz-dolerite facies (21594, 22306). Here, however, the effects of metamorphism are even more obvious, and except for remnants of crystals of basic plagioclase, no original constituent remains. The original and partially resorbed felspars give to the rock a microporphyritic aspect, while the matrix is fine-grained, dark-coloured, and finely crystalline in texture. Microscopically it is seen that the larger original felspars have been shattered, resorbed, and acidified by the growth of albite-oligoclase and orthoclase on their peripheries, as also internally wherever any flaw laid them open to attack. The matrix is a moderately coarse pyroxene-granulite composed of granular augite and rhombic pyroxene, scattered magnetite, small crystals of acid plagioclase, and moderately abundant biotite, in a base of alkali-felspar and quartz. The acid matter has locally collected into well-defined interstitial areas where it exhibits a beautiful micrographic structure. In some cases (22306), the rhombic pyroxene (hypersthene) builds relatively large crystals that behave ophitically with respect to the small recrystallized felspars of the matrix.

In this portion of the gabbro-mass the results of thermal metamorphism are most apparent. The whole rock, with the exception of the larger felspars, has suffered recrystallization, and even these felspars have been modified to a considerable extent.

The Porphyritic Gabbro (D, *see* p. 294).—Although the greater portion of this gabbro, which forms the southern end of the screen, has suffered great metamorphic changes, there are areas, situated some distance from the junctions with later intrusions, in which the original nature of the mass can be demonstrated. Such areas yield rocks of eucritic nature in which fresh olivine is a plentiful constituent (22661), occurring as large irregularly bounded crystals. It is associated with augite, hypersthene, and basic plagioclase, and the rock has a typical gabbroid structure. The augite occurs as subophitic to hypidiomorphic crystals and aggregates that exhibit a poorly developed diallagic structure, and frequently show signs of granulitization. It is often in association with a strongly pleochroic hypersthene that occurs as moderately large crystals. The ferromagnesian constituents are set in a wholly felspathic matrix that is composed of fairly large crystals of basic labradorite and a mass of smaller recrystallized individuals of similar composition. Such rocks certainly represent the original gabbro, which, though granulitized to some extent, retains to a considerable degree its original structure. Close against the Great Eucrite, however, the gabbro passes into a completely recrystallized rock of finer texture (Fig. 31 A, p. 230), which might be termed an olivine-gabbro-granulite The gabbro in this form consists of a granulitic mass of augite, olivine, labradorite, and magnetite, in which olivine is more abundant near to the junction with the less altered gabbro. The felspar is clear and free from inclusions. Hypersthene is a common constituent of most of these gabbro-granulites and is evidently a product of metamorphism.' It occurs intergrown with augite, and also as isolated crystals and subophitic patches, in a matrix of completely recrystallized felspar that contains abundant granules of pyroxene.

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[1] The peculiar cloudiness of felspars, induced by metamorphism, has been discussed at some length by Mr. A. G. MacGregor in 'The Geology of North Ayrshire,' *Mem. Geol. Surv.*, 1930, pp. 50, 51.

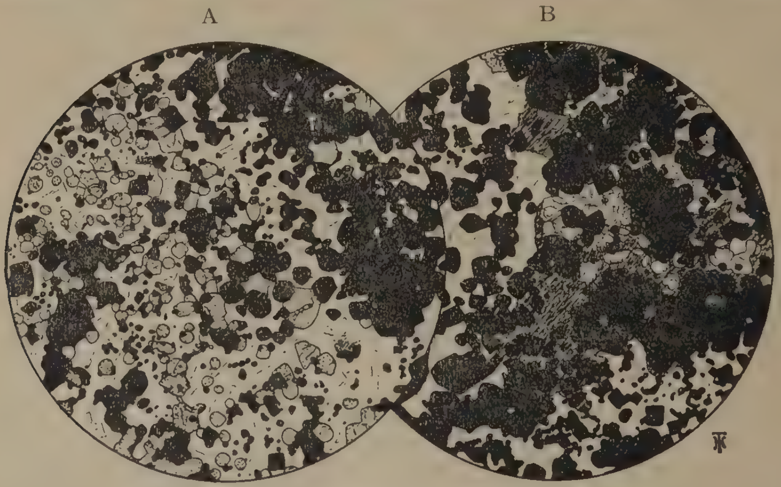


FIG. 43.—*Olivine-spinel-granulite.*

A. (26671)×20. *The rock consists of rounded grains of olivine and an almost opaque dark-green spinellid in a matrix of basic plagioclase felspar.*
B. (26671)×20. *Another portion of the same section, with the same magnification, showing the large plates of biotite that occasionally replace felspar as the matrix of the other constituents.*

In the fine-grained granulites a banding, probably due to partial fusion, is a conspicuous feature near and at a junction with the

Great Eucrite (p. 300). The constituent minerals are mainly the same as before, namely, augite, hypersthene, magnetite, and labradorite, but the chief differences lie in the absence of olivine, the parallel orientation of the felspars, and in the alternation of finely and coarsely crystallized material from band to band (22657, 22659).

Close to the Outer Eucrite, on the eastern side of the screen, some very beautiful olivine-spinel-granulites have been detected (26671) (Fig. 43). These evidently result from the reheating of an allivalitic gabbro. They are rocks in which there is considerable and rapid variation both in texture and in composition. This variation is determined, not by the occurrence of different minerals, but by the relative sizes and concentration of the same constituents. The coarser and more felspathic portions of the rock consist of a mosaic of bytownite that encloses moderately abundant colourless olivine with subordinate augite and green spinel. The finer-textured portions are composed of a similar mosaic of felspar densely packed with granules of olivine, and octahedra and rounded grains of dark-green spinel (pleonaste-hercynite). The felspar of the matrix occasionally gives place to large all-embracing plates of red-brown biotite (Fig. 43 B). The source of the potash required for the formation of biotite is probably to be attributed to alkali-felspar that had been introduced into the original rock in the form of an alkali-felspar and quartz magma, prior to the metamorphism of the gabbro.

It is interesting to note the petrological similarity of this granulitized gabbro of the Meall nan Con screen to the lenticles and schlieren of granulitic character which occur in the marginal portion of the Hypersthene-gabbro of Centre 2 (p. 229), as well as in the peripheral portions of the Great Eucrite (p. 308).

The Basalt–Agglomerate Screen West of Faskadale

Petrology

The rocks forming this screen are highly granulitized, and as basaltic material enters largely into its composition, both as lavas and agglomerate, pyroxene-granulites preponderate. The basaltic material has passed over to fine-textured pyroxene-granulites (26740), in which a rhombic pyroxene as well as a monoclinic variety is abundantly developed. In such rocks a few of the larger felspars retain their original form, but have suffered albitization and some recrystallization. Biotite, in association with rhombic pyroxene, occurs in restricted areas, and probably occupies approximately the position of original olivine.

The screen is traversed by acid veins, many probably emanating from the Great Eucrite, and the thicker of these are of granophyre with very beautiful micrographic structures (26738), ranging from an extremely fine intergrowth that is exhibited by perthite-quartz phenocrysts to a coarse graphic growth in the surrounding matrix. Normally they are quartzo-felspathic rocks without any original ferromagnesian minerals, and carry little in the way of accessories. Others, which appear to have been modified by the absorption of basic material (26739), consist of a coarse mosaic of albite-perthite with interstitial quartz, which includes large plates of biotite (partly chloritized), irregularly bounded crystals of greenish-brown pyrogenetic hornblende, and a few small almost colourless crystals of augite edged with uralitic hornblende. Finely divided magnetite is fairly abundant in association with the hornblende, and is presumably a result of basification. Some of the narrow acid veins that traverse the completely granulitized portions of the screen, and which in all probability were primarily of granophyric composition, have developed abundant stumpy crystals of rhombic pyroxene and oligoclase in an alkali-felspar base. H.H.T.

(F) Quartz-gabbro of Meall an Tarmachain Summit

This mass forms the central peak of Meall an Tarmachain, and is for the most part a quartz-gabbro with well-developed acid mesostasis. Olivine is present as a rule, and where the acid mesostasis becomes sparse the rock approximates to eucrite. Exposures are generally good, but fail along the greater portion of the margin. Two contacts, however, have been established, one with the Outer Eucrite (E′), the other less well seen with the Great Eucrite (E). The contact with the Outer Eucrite is situated 200 yds. E. 30° S. of the summit. The Quartz-gabbro becomes rapidly finer grained towards its irregular junction with the coarser textured Eucrite, and encloses xenoliths of eucrite (Fig. 44). There can be no doubt as to the relative ages of the two rocks in contact. A junction with the Great Eucrite was located in a corrie west of the central peak, 400 yds. W. 10° S. of the summit, on the north side of a stream that flows south-west. The Eucrite is a rather felspathic type, but is coarse-textured and shows no signs of chilling at the junction. The Quartz-gabbro possesses a well-fluxioned edge against the Eucrite. The fluxioned felspars are steeply inclined parallel to the slightly irregular plane of junction of which 3 ft. in depth is seen. The Eucrite is not appreciably baked (22683). A fine-grained vein apparently derived from the Quartz-gabbro crosses the Eucrite (*see also* p. 301).

About a quarter of a mile north of Meall an Tarmachain summit, small masses of porphyritic quartz-dolerite are surrounded by the Great Eucrite. The rock composing them is unbaked (22685), and they are concluded to be later than the Eucrite. Possibly they are offshoots from the neighbouring Quartz-gabbro (F). J.E.R.

Petrology.—The gabbro is a moderately coarse doleritic rock composed essentially of labradorite and a subophitic augite, both minerals having an equally coarse type of crystallization (22689), with subordinate magnetite. A few pseudomorphs in serpentine and magnetite represent original olivine. There is usually some acid mesostasis and also well developed acid veins, which have produced marked albitization of the adjacent felspar (Fig. 45 B), and which have crystallized as a mosaic of perthitic alkali-felspar and quartz. Towards the Great Eucrite (E), the rock assumes the character of a moderately coarse fluxioned quartz-dolerite or gabbro

(22683), but at its contact with the Outer Eucrite (E′) it becomes finer in texture and distinctly porphyritic (22688), the felspars measuring up to half a centimetre in length. The porphyritic individuals are of a strongly zoned optically positive labradorite that shows strong marginal reaction effects and a final marginal growth of oligoclase. The matrix consists of subophitic to subcolumnar augite and hypidiomorphic crystals of labradorite, which, like the porphyritic felspars, are edged with oligoclase. Magnetite is moderately abundant as irregularly scattered grains, and there is a little mesostasis that has effected the usual changes in the earlier-formed constituents.

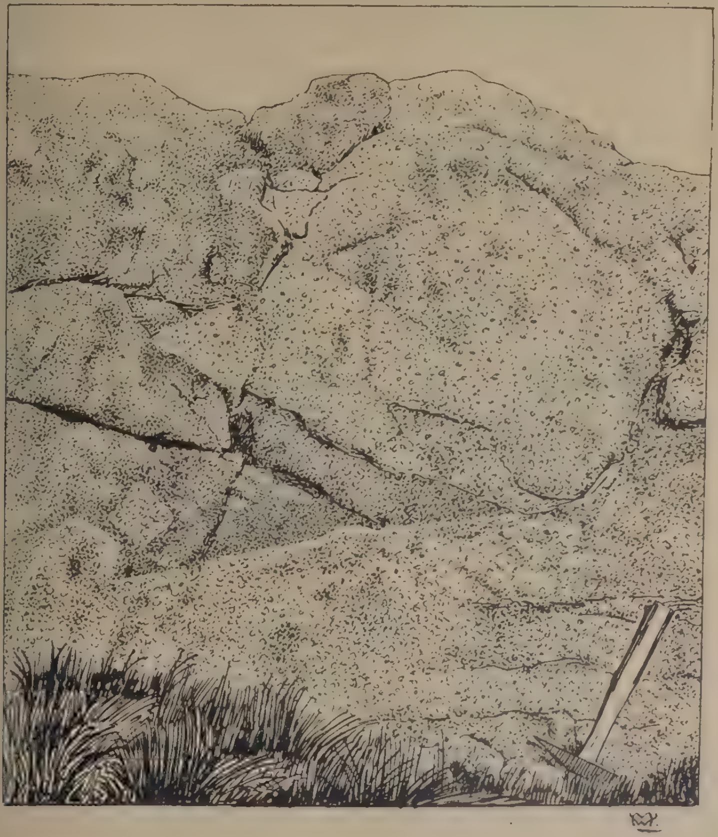


FIG. 44.—*Intrusive Junction of Quartz-gabbro of Meall an Tarmachain (left) with Outer Eucrite, south-east side of Meall an Tarmachain.*

Drawn from Geological Survey Photograph No. C. 2812.

A similar fine-grained porphyritic type (22685), which occurs to the north of Meall an Tarmachain, shows an augite with a much more pronounced ophitic tendency, and in addition to pseudomorphs after olivine contains abundant partly decomposed crystals of hypersthene. Biotite occurs in association with the augite and also with the iron-ores, and it is probable that the rock has suffered some metamorphic change.

The mass, to the north of Meall an Tarmachain, is separated from the Great Eucrite by a narrow screen that is mainly composed of agglomerate, but which, at its north-east end, includes granulitized olivine-bearing quartz-dolerite (22684) (p. 301). The latter rock contains a moderate amount of acid mesostasis in the form of alkali-felspar, and lakes of alkali-felspar and quartz in graphic intergrowth. It is also traversed by veins of acid composition. H.H.T.

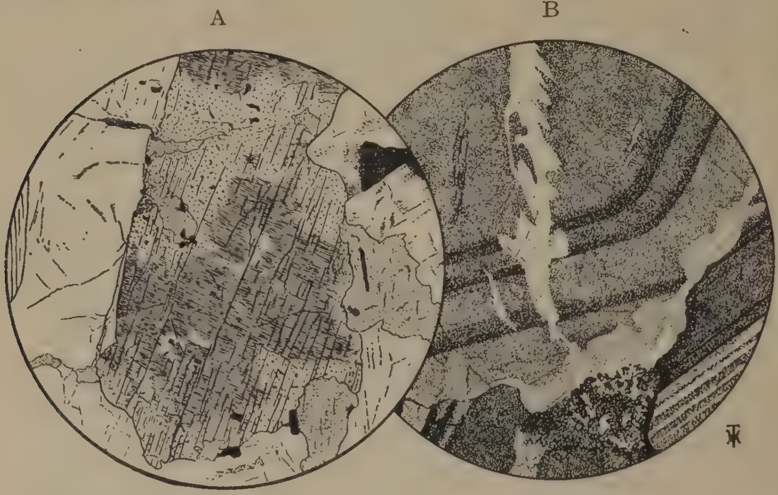


Fig. 45.

A. (22345) ×20. *Large crystal of augite showing the local obliteration of schiller-structure as one of the results of acidification* (p. 276).

B. (22351) ×23. *Zoned crystal of basic plagioclase fringed with a late crystallization of albite-oligoclase and veined by albite. Crossed nicols.*

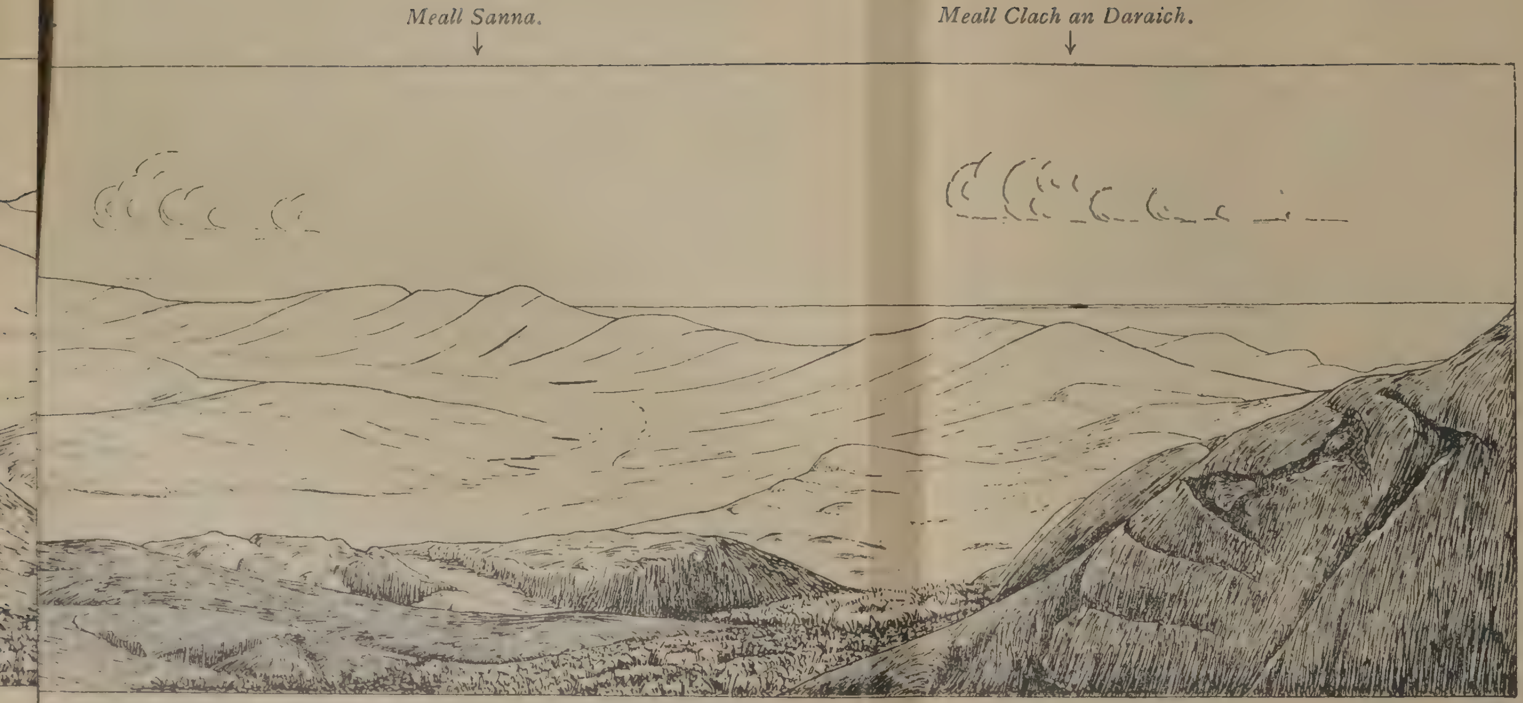
(F′) Quartz-gabbro, South Side of Meall an Tarmachain

South of the central peak of Meall an Tarmachain, a ridge of quartz-gabbro extends southwards. It is bounded to the east by the Outer Eucrite and to the west by the large capping of basalt lavas and agglomerates. On the north, it is separated from the Quartz-gabbro (F) by a continuation of the rocks of the capping, which extend up the hillside in screen-like fashion.

This mass passes into a fuzzy-weathering quartz-dolerite at its margins to west and north. It appears to be breaking through the capping to the west, for the base of the capping abuts against the base of the ridge formed of the Quartz-gabbro. Its age relative to the Outer Eucrite (E′) is unknown.

To the south, the Fluxion Gabbro of Faskadale is mapped as a separate intrusion from the Quartz-gabbro (F′), on account of the difference in composition of the two rocks, though no contact between them was located. J.E.R.

PLATE VI.


Meall Sanna.
Meall Clach an Daraich.

Tarmachain and Beinn na Seilg in distance.
hill an. The distance from Meall Meadhoin across the Interior Complex to Meall Sanna is three miles.

CHAPTER XXI

TERTIARY RING-DYKES OF CENTRE 3, ARDNAMURCHAN—(*continued*)

THE ring-dykes that remain to be described comprise the Interior Complex, which is surrounded by the Great Eucrite, and are as follows (*see* Index Map, p. 201) :—

(G) Biotite-eucrite.
(H) Inner Eucrite.
(I) Quartz-dolerite veined by Granophyre.
(J), (J′), and (J″) Quartz-biotite-gabbros.
(K) Fluxion Biotite-gabbro of Sìthean Mòr.
(L) Fluxion Biotite-gabbro of Glendrian.
(M) Tonalite.
(N) Quartz-monzonite.

The area around Achnaha occupied by the Interior Complex is noteworthy on account of its ring-featuring. Its outer limit is set by the conspicuous circle of crags that mark the inner side of the Great Eucrite (*see* Pl. VI). The base of these crags closely coincides with the outcrop of the narrow granophyre-veined Quartz-dolerite Ring-dyke (I), while the actual inner margin of the Great Eucrite deviates slightly on either side of this intrusion. The curving ridges of Sìthean Mòr and of Glendrian, the latter forming a practically complete ring, correspond to individual intrusions of fluxion biotite-gabbro (K) and (L). In the intervening hollow, on the south side of the Interior Complex, two other gabbros lettered (H) and (J) can be distinguished. One of them (H), termed the Inner Eucrite, along the eastern and western parts of its arcuate outcrop forms a low curving ridge flanked by less durable rocks. The Glendrian ring-ridge just mentioned is illustrated in Pl. VI surrounding a central area of lower relief, which is chiefly occupied by the Tonalite (M). Rising ground in the middle of this area is formed of a small mass of Quartz-monzonite (N). Perhaps the clearest demonstration that we are dealing with a complex of ring-dykes is afforded by the narrow Quartz-dolerite intrusion (I). Its ring-pattern is evident, and there is no doubt that it is steeply intruding the rocks traversed by it.

Time relations between many of the gabbro masses cannot be determined. Two ring-dykes can, however, be proved to be later than the Great Eucrite, viz. the Quartz-dolerite (I) and the Fluxion Biotite-gabbro of Sìthean Mòr (K). An apophysis from the outer side of (K) manifestly cuts the Great Eucrite, but on its inner side no evidence is forthcoming as to its age relations with the Inner Eucrite (H). The Inner Eucrite is with some hesitation regarded as a distinct intrusion from the Great Eucrite, and not merely as a portion of the latter, separated by younger intrusions. An element of doubt also attaches to the Fluxion Biotite-gabbro of Glendrian (L), as to whether it is a distinct intrusion from the similar rock of Sìthean Mòr; for no age relations have been with certainty established between them and the intervening intrusions (H) and (J). The Glendrian Ring-dyke is, however, in sharp contact with the Quartz-biotite-gabbro (J) outside it, and contains small masses of quartz-biotite-gabbro which may be interpreted as xenoliths derived from its walls. If this view be correct, these Glendrian and Sìthean Mòr masses are distinct intrusions. It would seem likely that the various coarse-textured Quartz-biotite-gabbros (J), (J′), and (J″), are all portions of a single intrusion that was split up by the Glendrian Ring-dyke (L) and the Tonalite (M). The Tonalite passes into a fine-grained marginal facies against the gabbros outside it, into which it is clearly intrusive. Cutting the Tonalite in turn there is the small central mass of Quartz-monzonite which marks the final episode of the Later Ring-dyke Complex.

(G) BIOTITE-EUCRITE

Biotite-eucrite forms a broad outcrop around the inner margin of the Great Eucrite (E), except to the north. It is noteworthy that a similar discontinuity to the north is a feature of various other ring-dykes of Centre 3. This in itself suggests that the Biotite-eucrite is a distinct intrusion.

The Biotite-eucrite differs lithologically from the Great Eucrite not only in containing biotite, but also in being for the most part more felspathic. The biotite is somewhat sporadic in its occurrence and is locally absent. There is no suggestion in the field, such as well-developed acid veining, that it has resulted by reaction, *in situ*, between normal eucrite and an incoming acid magma. Sparsely developed acid veining appears to be a late derivative from the mass itself, and is richer in biotite than the normal rock. An example may be seen in the Allt Màm a'Ghaill (21478).

Perhaps the best locality for judging the distinctness of the Biotite-eucrite from the two intrusions that chiefly bound it, the Great Eucrite and the Inner Eucrite, is alongside the track that leads from Achnaha to Plocaig. A vertical junction with the Inner Eucrite is exposed on the east side of the track, 530 yds. north-west of Achnaha. The Inner Eucrite is easily distinguished from the Biotite-eucrite, since it is in this part of its course of medium grain, fluxioned, and olivine-rich. At the contact seen, no evidence of relative age could be obtained; for neither rock shows any appreciable marginal change against the other. The Biotite-eucrite is frequently exposed alongside the track from this point on to a ford across an easterly branch of the Allt Sanna. Just north of the ford, biotite-eucrite is abruptly succeeded by normal eucrite which is mapped as part of the Great Eucrite. No actual intrusive contact, however, is discernible, but this is not surprising since the two rocks do not differ in texture. Another locality may be mentioned, viz. alongside the Kilchoan–Achnaha road where it curves around

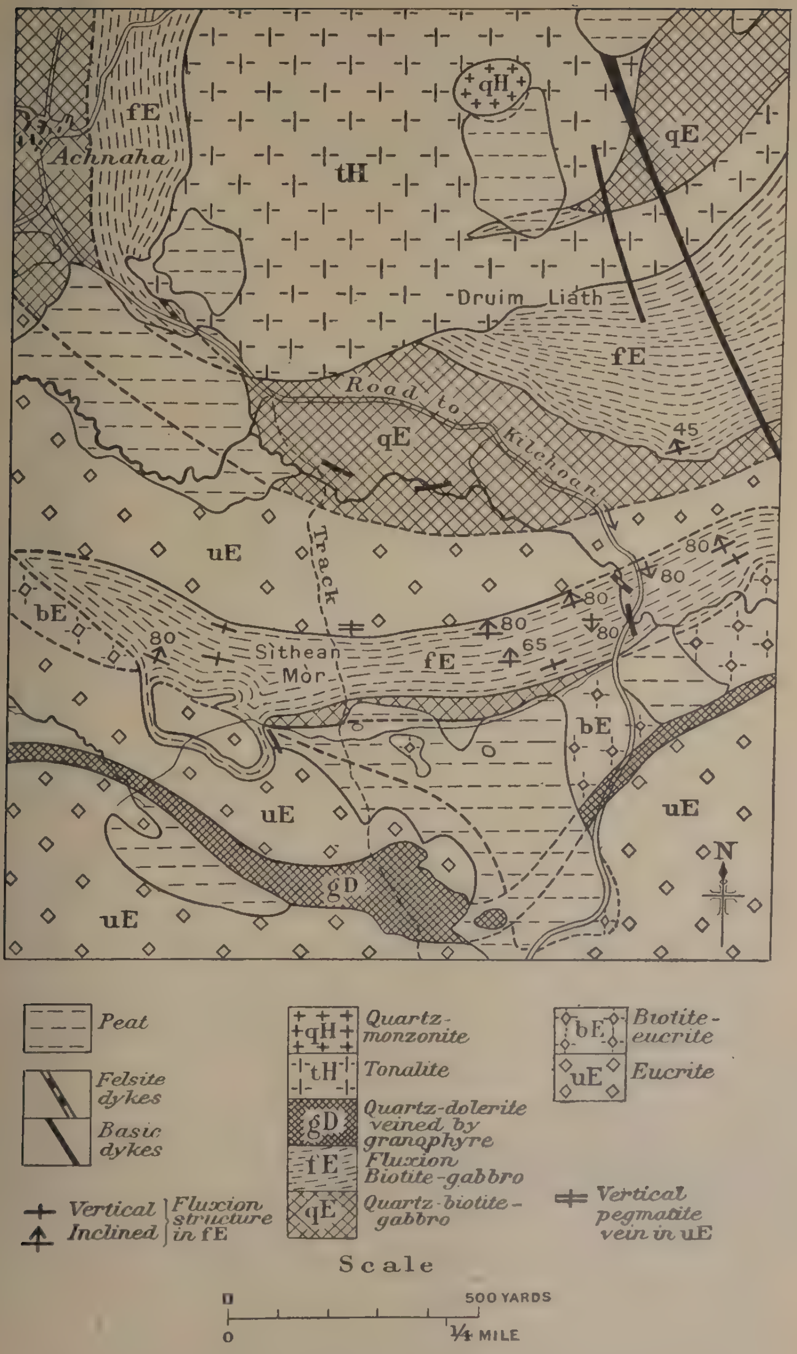

fE
Achnaha
tH
qH
qE
Druim Liath
fE
Road to Kilchoan
qE
45
uE
Track
bE
80
Sithean Mor
fE
80
65
80
80
80
80
bE
uE
uE
gD
uE
N
Peat
Felsite dykes
Basic dykes
Vertical
Inclined
Fluxion structure in fE
qH Quartz-monzonite
tH Tonalite
gD Quartz-dolerite veined by granophyre
fE Fluxion Biotite-gabbro
qE Quartz-biotite-gabbro
bE Biotite-eucrite
uE Eucrite
Vertical pegmatite vein in uE
Scale
0
500 YARDS
0
¼ MILE

Fig. 46.—*Map of south portion of Interior Complex of Ring-dykes (Centre 3).*

a peaty flat, west of Creag an Airgid. There also, though both types of eucrite are found in close association, no intrusive relationship could be discerned. Along the eastern limb of the Biotite-eucrite, as mapped, its margins against the Eucrite intrusions on either side have been only approximately determined. The Biotite-eucrite forms smooth, poorly exposed ground between ice-smoothed rocky country that marks the outcrops of the Eucrites. J.E.R.

Petrology (Anal. I, Table IV, p. 85).—This mass as represented by specimens collected from its southerly outcrop, to the east of Sìthean Mòr, is definitely eucritic in nature (21479), and from this region material was collected for chemical analysis (21250). It is a moderately coarse, fresh gabbroid rock of general grey tint, composed essentially of a greasy-looking greyish felspar with bright cleavage-faces, and augite that occurs as somewhat irregular dark crystals and patches. The felspar is usually in excess of the pyroxene, but the dimensions of the respective crystals are approximately the same, and range up to one or one and a half centimetres in greatest length.

Microscopically the structure and the mineral-assemblage are those of the eucrites. Olivine occurs in a practically undecomposed condition. It is not a particularly abundant mineral, but when present builds rounded crystals several millimetres in diameter, which are usually of earlier consolidation than the felspar, although they may occasionally enclose small crystals of bytownite of earlier generation. The bulk of the felspar is, however, a much twinned but unzoned basic labradorite. It usually shows some slight mottling with a variable extinction, and is also strung to a varying degree with albite. The analysed specimen (21250) shows the mottling of the felspars to great advantage, and also suggests that individual crystals have suffered resorption followed by a regrowth of felspar of less basic composition.

Augite of a somewhat dirty brown colour forms large ophitic patches and is moulded upon both olivine and felspar. In addition to the monoclinic pyroxene, hypersthene is a moderately abundant constituent. It occurs in association with olivine, and as fairly large irregular ophitic crystals moulded upon felspar. Iron-ore is not very abundant but is usually present as large ill-formed patches, which, in the analysed rock, are fringed with biotite that, with a colourless amphibole, forms a narrow reaction zone between the iron-ore and contiguous labradorite.

There is little doubt that the rock, as represented by the analysed specimen, has suffered some slight change from its original condition. This is suggested by the mottled appearance and local reduction in basicity of the felspars, by the interaction of iron-ore and felspar with the production of biotite and hornblende, by the relative abundance of rhombic pyroxene, and by the fact that apatite, which is of rare occurrence in the most eucritic types, becomes prevalent in those which carry hypersthene. Some modification of the rock as the result of reheating is also suggested by the occurrence of small granulitic patches within the felspars, which are made up of minute granules of biotite, rhombic pyroxene, hornblende, and magnetite.

Although much of the mass is definitely eucritic and carries olivine, there are portions which are more augitic and are composed essentially of an ophitic diallagic augite and labradorite (21809). That the bulk of this biotite-eucrite owes its biotitic and other somewhat abnormal characters to the influence of an acid partial magma is made clear by specimens collected from various parts of the mass. In nearly all instances an acid mesostasis can be detected, and in many cases it bulks largely in the composition of the rock. It then forms a mass of turbid and often graphic perthitic felspar and quartz which carries abundant apatite (21497). The effect of this acid material has been to cause the resorption and albitization of the basic felspars and a regrowth of acid fringes at their peripheries. Also, where contact has been effected with augite, hornblende and biotite have been developed. The albitization of the basic felspars is frequently in a net-like form, in which fine strings of albite appear to follow intersecting lines of fracture in the original mineral (21487). It would appear that this fissuring of the felspars is due to a similar cause to the shattering observable in some of the other rock-masses (p. 268), but had not reached such an advanced or intense stage (21546, 21476). The effects are confined to the production of a network of cracks and the occasional bending and displacement of twin lamellæ (21475). This incipient disruption is in all cases followed by albitization, both phenomena being in all probability due to the pressure exerted by the crystallization of an acid magma that was charged with volatile constituents. Local hybridization of basic by acid material has produced certain mineral changes without the destruction of the general gabbroic composition and structure of the original rock. The chief changes, where the acid material is most in evidence, are the separation of large plates of biotite (21497), the development of hornblende at the expense of augite, and the albitization of the original labradorite felspars. Where the action is less pronounced the effects are mainly the local deschillerization of the original diallagic augite, the production of uralitic hornblende, and the development of rhombic pyroxene in association with olivine. Such changes as these were effected on a rock that was evidently almost solid, and therefore complete interaction was outruled; but we encounter within the mass rocks that exhibit the characters of true hybrids, and in which the acid magma has sunk its identity by reason of almost complete interaction with basic material. In some cases a more or less normal gabbroic rock may be seen to pass rapidly into one of much finer texture (21486), which contains moderately abundant biotite (chloritized), recrystallized augite, a good deal of iron-ore, intensely albitized remnants of basic plagioclase, and abundant apatite, in a granophyric matrix of perthitic orthoclase and quartz.

Two other abnormal types have also been detected. One is a moderately fine-grained rock, occurring as veins (21478) and presenting characters reminiscent of the Tonalite and Quartz-monzonite of Centre 3 (p. 338). It consists of hypidiomorphic augite, large plates of biotite, pseudomorphs after rhombic pyroxene in fibrous hornblende, generally acidified and recrystallized plagioclase felspar and large apatites, in a matrix composed of perthitic orthoclase and quartz.

Another type, also fine-grained and occurring as narrow strips along the road between Achnaha and Plocaig (22262), has a doleritic texture. It contains an abundance of augite that has assumed an ophitic, with an approach to a cervicorn,[1] structure. It has developed large areas of ophitic hypersthene and large plates of biotite that is moulded upon felspar. The felspars are elongated individuals with a prismatic to platy habit, and have a composition varying from labradorite to oligoclase. There is a small amount of acid mesostasis containing alkali-felspar and a little residual quartz, and moderately abundant magnetite that occurs mainly in association with the rhombic pyroxene. H.H.T.

(H) INNER EUCRITE

It cannot be demonstrated whether the Inner Eucrite is a portion of the Great Eucrite or a distinct intrusion. There is, however, a sharp contact with the Biotite-eucrite (G), as described above (p. 322).

In its eastern portion the Inner Eucrite forms a slight curving ridge, and further evidence of its arcuate shape is there provided by the changing directions of longitudinal pegmatite veins that traverse it. The veins are found as far north as the point where the Inner Eucrite and Great Eucrite come together. Exposure here becomes poor, but at one place, west of a patch of peat and 500 yds. south-east of the summit of Meall Clach an Daraich, outcrops are more continuous. A steep junction was noted there between olivine-rich eucrite of fairly fine grain (perhaps the inner margin of Great Eucrite) and coarse-textured felspathic eucrite with large irregular olivine-aggregates (perhaps the outer margin of Inner Eucrite). The relative ages, however, of the two rocks in contact could not be ascertained. Southwards, east of the Kilchoan–Achnaha road, eucrite with pegmatite veins gives place westwards, along the course of the ring-dyke, to eucrite with fluxioned felspars, a type that is difficult here to separate from the adjoining Fluxion Biotite-gabbro of Sìthean Mòr (K). Farther west, however, along the north side of the curving Sìthean Mòr ridge, these two masses are quite distinct in rock-type. The Inner Eucrite next to the Fluxion Biotite-gabbro is here fairly fine grained, is rich in olivine, and contains pegmatite veins, while a few yards away towards its interior it becomes an extremely coarse-textured rock with large plate-like augites. West of Achnaha, normal eucrite forms a low curving ridge that is bordered externally by fluxion eucrite. North of Achnaha, alongside a track leading to Plocaig, this fluxion rock is especially well exposed and contains abundant olivine in crystals or crystal-aggregates arranged parallel to the direction of flow. It may be remarked that the prevalence of olivine and absence of biotite usually serve to distinguish fluxion eucrite from fluxion biotite-gabbro.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 302.

It is not certain whether this fluxion eucrite forms an integral part of the Inner Eucrite. Gradation from the normal type into the fluxion eucrite seems, however, to take place. J.E.R.

Petrology.—This ring-dyke is composed of an olivine-rich rock most nearly comparable with the basic portions of the Great Eucrite (E). It has often approximately the same texture as the Great Eucrite, and appears for the greater part to be unmodified. It consists of fresh olivine, diallagic augite, and felspar, ranging in composition from labradorite to bytownite. The olivine is the usual magnesian-iron variety, which is of early consolidation but, like the olivine of the Great Eucrite, frequently encloses small rounded crystals of early felspar (21481). It occasionally has hypersthene developed in close association with it, a development that is marked by the separation of magnetite in dendroid form (21492). The mass as a whole appears to be more uniformly basic than the Great Eucrite and occasionally is definitely allivalitic in composition (21547). In such cases the rock consists essentially of olivine and basic plagioclase, augite being quite subordinate. H.H.T.

(I) QUARTZ-DOLERITE VEINED BY GRANOPHYRE

As already mentioned (p. 321), this narrow, curving outcrop of quartz-dolerite furnishes the clearest example of a ring-dyke within the Interior Complex. Contacts with adjoining rocks provide evidence of its distinctness as an intrusion and of its steep dyke-like form. Occurring as it does, exactly at the foot of the Great Eucrite scarp, it was there identified at an early stage in the mapping of the Interior Complex, and was the first good evidence to be obtained in Ardnamurchan of the ring-form of the major intrusions.

The characteristics of this composite intrusion are similar to those already described in the case of the ring-dyke of Sgùrr nam Meann (e) (p. 256). The main differences are that biotite is of general occurrence in the doleritic portion of (I), and that the granophyre occurs in thicker net-veins. The restriction of the acid net-veining to the narrow outcrop of the ring-dyke is a most remarkable feature. The walls of the intrusion are nowhere veined, though the granophyre was intruded subsequently to the consolidation of the quartz-dolerite. Sometimes the granophyre forms distinct masses between the doleritic portion and the wall, or may even occur alone, as at the north-west extremity. The two stages of magma-injection were therefore restricted to the same ring-fracture. The quartz-dolerite was intruded, became consolidated, and was then brecciated before the granophyre magma entered its cracks and fissures. The quartz-dolerite grades rapidly in places from the normal basic rock to a more acid type, but is everywhere in sharp or hybridized contact with the veins of granophyre. The granophyre cannot be a late segregation product of the crystallization of the quartz-dolerite, at any rate at its present exposed level.

The replacement of the normal net-veined quartz-dolerite by a breccia composed of the rocks forming its walls has been already briefly described (pp. 212–3). This occurs at the north-eastern termination of the Ring-dyke, and furnishes an indication of its mode of intrusion.

The most extensively exposed contact between the intrusion and its wall is on its eastern side, just north of the outwardly projecting arm of the intrusion shown on the Memoir-map. The outer margin of the Quartz-dolerite, varying greatly in composition, can be traced to a chilled edge against the Great Eucrite. The plane of junction is well exposed on a steep face of eucrite, and though somewhat irregular is, taken as a whole, inclined eastward at about 70 degrees, outwards from the Achnaha Centre (3). Other chilled junctions may be seen farther south and west, for example in the tributary stream south-west of the Allt Màm a'Ghaill, on the outer margin of the Ring-dyke. Along its inner margin in this stream, granophyre forms a mass distinct from the quartz-dolerite portion, and presents a vertical unchilled contact against the Biotite-eucrite within it. In the Allt Màm a'Ghaill, the quartz-dolerite portion is separated from both walls by granophyre, by which the dolerite is abundantly net-veined. In contrast, the granophyre sends broad tongues into the walls of Biotite-eucrite on either side, but does not net-vein them. J.E.R.

Petrology.—A considerable portion of the mass has the appearance of a moderately fine-grained quartz-dolerite (21495), but the development of much uralitic hornblende and fairly abundant biotite suggests a hybrid origin. More localized portions of the intrusion are definitely of hybrid nature (21496); and consist of a mass of short prisms of labradorite and patches of less basic plagioclase enveloping occasional large crystals of albitized basic plagioclase, an abundance of small hypidiomorphic crystals of augite, uralitic pseudomorphs after rhombic pyroxene, clots of brown-green hornblende with occasional biotite, and abundant magnetite.

The acid veins that string through the more basic portions of the intrusion show evidence of basification. They are granophyres (21536, 22263) that consist mainly of perthitic alkali-felspar and quartz, the former often tending towards a porphyritic development. A plagioclase felspar, however, with strongly acidified margins is occasionally present. Relics of basic material exist in the form of irregular patches of iron-ore, hornblende, and pseudomorphs after biotite. The quartz–felspar matrix exhibits a coarse and somewhat ill-defined graphic structure. H.H.T.

(J), (J′), AND (J″) QUARTZ-BIOTITE-GABBROS

Quartz-biotite-gabbro occurs in three distinct masses separated by two intrusions both probably of later date (p. 322). The rock is very variable in grain, but for the most part extremely coarse-textured and comparable to pegmatite. In containing iron-ore, in large crystals, and biotite, it differs from eucrite; while quartz can usually be seen in the more acid, felspathic, portions or in drusy cavities. Olivine is frequently present, and in some places the rock approaches eucrite in composition. Epidote is often developed, usually in the more acid quartz-bearing portions.

As already stated, it is considered probable that the three masses here described together are parts of one intrusion. In the case of the two inner masses (J′) and (J″), this is practically certain, for they are separated only by the Tonalite, which is demonstrably of later date. Their former connexion with the outermost and largest mass (J) is not improbable. This mass is separated from (J′) by the Fluxion Biotite-gabbro (L) which appears, by such evidence as is available (p. 334–5), to be later than (J).

While the distinctness of the two larger masses, (J) and (J′), from adjoining intrusions is evident at many places, it should be stated that, in the eastern parts of both, great difficulty was experienced in the field in separating them from adjoining gabbros. The difficulty is, partly at least, a matter of sparseness of good exposure. Possibly, however, had more time been available, the mapping in this part of the area, around Glendrian farm and farther east, might have been improved.

The screen-like mass (J″) is mapped as a unit but, besides the normal coarse-textured gabbro, includes a finer-grained type that may belong to another intrusion (*see* p. 337). J.E.R.

Petrology (Anal. VI, Table IV, p. 85).—The mass (J) is identical in character, and presumably in origin, with the gabbro-screen in the Tonalite (J″, p. 340) and with the Quartz-biotite-gabbro (J′). The original rock would appear to have been an olivine-gabbro. Representative specimens (21480) exhibit albitization of basic felspar and formation of biotite from augite and iron-ore, while there is the usual concentration of apatite. Micrographic alkali-felspar and quartz fill the interstices between the larger crystalline constituents, and are presumably referable to a hybridizing partial magma.

The mass (J′) is a moderately coarse augitic gabbro that has suffered considerable modification. The changes that the gabbro has experienced are the intense albitization of the basic plagioclase (21538), the deschillerization of the augite with the formation of spangles of biotite and hornblende-fringes, and the introduction of an apatite-rich alkaline and siliceous magma that has crystallized as perthitic orthoclase and quartz (21477). Olivine was occasionally an original constituent of the gabbro (21256). Biotite has been developed, usually at the expense of original iron-ore. H.H.T.

(K) FLUXION BIOTITE-GABBRO OF SÌTHEAN MÒR

This arcuate mass forms the curving steep-sided ridge of Sìthean Mòr, and also extends eastwards across the Kilchoan–Achnaha road. It is separated from the Glendrian Ring-dyke (L), which is similarly composed of fluxion biotite-gabbro, by the Inner Eucrite (H) and the Quartz-biotite-gabbro (J), as already mentioned (p. 321).

The rock is typically medium-grained and dark in colour, and its felspars are markedly fluxioned. Biotite is plentiful, and also iron-ore in small crystals. In the middle part of its course, west of the Kilchoan–Achnaha road, the intrusion, as mapped, consists of three portions, the normal fluxion gabbro on the north, coarse-textured quartz-biotite-gabbro on the south, and an intervening portion composed of the two bordering gabbro-types in alternating bands (Fig. 47). The coarse gabbro weathers white and thus contrasts with the darker-weathering fluxion gabbro ; biotite is plentiful and quartz easily detected. It is, in fact, exactly similar to the Quartz-biotite-gabbro last described (p. 328).

In the banded portion, individual bands are usually inclined inwards towards the Achnaha Centre (3), but are sometimes vertical or inclined outwards. Where inclined, the angle is always steep.

The banding phenomenon is quite different from that found in the Hypersthene-gabbro (a) for example (p. 221), which is due to flow-movement during the crystallization of a homogeneous magma. The bands are too wide, and besides they are formed of two distinct rock-types. In this banded zone a third rock-variety occurs which bears a resemblance to the other two, and seems to have resulted from their intermixture ; for the banding becomes indistinct in this apparently mixed rock. The banding is best seen at a point 200 yds. west of where the intrusion is crossed by the Kilchoan–Achnaha road. There, on the inner or northern side of the intrusion, the normal type, a medium-grained dark-coloured fluxion biotite-gabbro, occurs alone. On the outer or southern side, coarse-textured unfluxioned quartz-biotite-gabbro is similarly developed as a rock-mass by itself. In the middle, banded zone, the conspicuous white bands of the coarse gabbro vary from an inch or so in width on the north side to a yard or more on the south side. These broad bands are sharply defined, and are seen to extend for many yards without change of direction or width. A similar variation in the width of the intervening bands of the darker gabbro also occurs, except that in this case the increase in width takes place towards the north. The widest bands are, in fact, found next to the mass to which they correspond in composition.

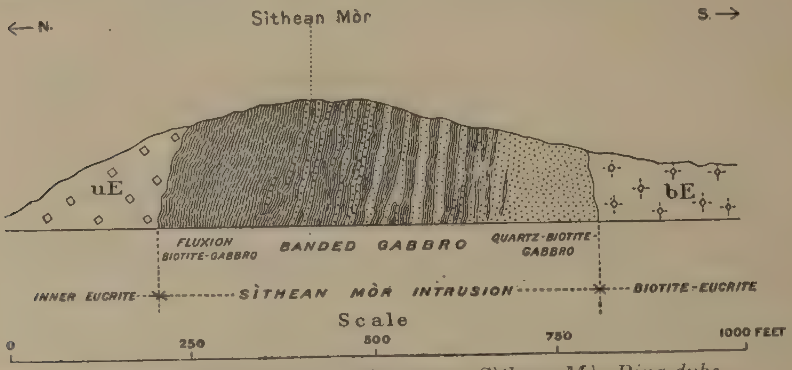

FIG. 47.—*Diagrammatic section across Sithean Mòr Ring-dyke.*

A variation in the character of the white gabbro bands is noteworthy. Where these are wide, the rock is coarsely or indeed very coarsely crystallized, and there is no fluxion arrangement of the minerals. In contrast, the associated bands of the darker gabbro show perfect fluxion arrangement of the felspar crystals, parallel to the edges of the bands. But, where the white gabbro is in thinner bands, their crystallization is finer and the felspars frequently show fluxion parallel to the banding. It is in this part of the banded zone that the banding often becomes indistinct, and the intermediate mixed type of gabbro is developed.

From the above observations the conclusion is drawn that two distinct magmas found their way into the same ring-cavity, and along their mutual junction formed a banded gabbro. The condition of these two magmas was different. The fluxion gabbro was evidently in a partially crystallized state while it flowed in interbanded fashion with the other magma. The narrower bands of the white gabbro, however, must have started to crystallize before flow-movement had ceased, since their felspar-crystals are often fluxioned. As already stated, it is in this part of the banded zone that intermingling of the two magmas appears to have often taken place, producing the intermediate type of gabbro. In the outer, southern part, where the magma that gave rise to the broad bands of white gabbro remained liquid till flow-movements had ceased, the individual bands are in perfectly sharp contact. It seems necessary to assume that the two magmas were here inhibited from mixing with one another. This may perhaps be in some way connected with the fact that the magma which formed the darker gabbro was in a partially crystallized state while the other remained altogether fluid.

Marginal Relations.—The Sìthean Mòr intrusion is of importance because of its marginal relations to the Great Eucrite (E). Half a mile west of the Kilchoan–Achnaha road an apophysis from it can be traced out into the Eucrite (Fig. 46). The protrusion consists of a fine-grained marginal portion in contact with the Eucrite, and a central more coarsely crystallized portion. The marginal portion presents a chilled edge to the Eucrite, and contains xenoliths of eucrite identical in texture with that forming its walls. Its later age is unquestionable. Yet this marginal portion appears in the field to be itself a baked rock, and is found in microscopic section to be granulitized. This apparent anomaly is of considerable interest. Between the two portions of the apophysis the change in texture is everywhere abrupt, and a sharp contact was located, at which the baking of the marginal rock is intense, while the coarser interior is apparently unbaked. Two stages in the infilling of the fissure are thus indicated. A first injection of magma cooled quickly as the fine-grained marginal rock, and was granulitized by a second injection forming the interior of the apophysis.

Further details concerning the apophysis may be added. At a point 700 yds. west of the Kilchoan–Achnaha road it extends out from the Fluxion Biotite-gabbro for a short way into the Eucrite, and then runs westwards for a distance of 250 yds. parallel to the parent mass, which it then rejoins. At this end it is very narrow, being only about 12 ft. wide, and the fine-grained marginal type occurs alone. Exposures are discontinuous for a few yards where the apophysis should connect on to the main mass, but they are so alike in rock-type, fine grained, fluxioned, dark, and with plentiful biotite, that their continuity cannot be doubted.

The small xenoliths of eucrite are found all along the outer marginal portion, which is well exposed. They are usually of normal eucrite, but at about the middle of the apophysis they consist of pegmatitic eucrite with large plate-like augites. At this point similar coarse-grained eucrite bounds the apophysis on its northern side, and it is therefore concluded that the xenoliths are derived from the eucrite forming the walls. A short way west of this the xenoliths are especially well seen, just east of a stone-wall that crosses the apophysis (Fig. 46), where they occur in all stages of disintegration. A chilled junction between marginal rock and eucrite was located to the north-west near to where the apophysis rejoins the main mass. The darker chilled skin of the marginal rock is easily seen in a hand-specimen. The internal junction between baked marginal rock and the central coarser type is exposed to the south-east, along the outer side of the apophysis, not far from where it branches from the main mass.

Though the junctions of the Sìthean Mòr intrusion with both the Biotite-eucrite (G) and Inner Eucrite (H) can be determined to within a few feet, no actual contacts have been found. Consequently the relative ages of these three intrusions are not known. Where the eastern arm of the apophysis branches from the main mass it is, however, in intrusive contact with a narrow outcrop of biotite-bearing eucrite or gabbro that would appear to belong to the Biotite-eucrite. There are therefore some grounds for considering the Biotite-eucrite to be earlier than the Sìthean Mòr intrusion.

Segregation-veins with ill-defined margins were noted in the Fluxion Biotite-gabbro in a small burn just east of Sìthean Mòr, south of where the Kilchoan–Achnaha road crosses a stream—the Allt Uamha na Muice. The rock contains large crystals of biotite and is akin to tonalite (21540). J.E.R.

Petrology.—This mass, from a petrological point of view, has much in common with the Biotite-eucrite (G), which it adjoins. These two intrusions, although demonstrably distinct, have undoubtedly a similar history, both being fundamentally eucritic in nature. The variable character of the Sìthean Mòr mass is presumably due to the hybridizing influence of an acid magma on a partially crystallized basic magma of eucritic composition. It presents characters that were encountered locally in the Biotite-eucrite, and it possibly represents a more advanced stage of hybridization than the adjoining mass exhibits. The mineral assemblages however, are similar in both cases.

Where the mass is obviously eucritic, it is a moderately coarse-grained basic gabbro (21482) that exhibits no serious modification of its original constituents. It is built up of large and small rounded crystals of olivine in close association with a coarsely ophitic brownish-green augite and large plates of much-twinned bytownite. Still recognisably eucritic, but in a modified condition (21537), the rock assumes the form of a coarse hypersthene-gabbro in which the place of augite is almost completely taken by rhombic pyroxene and uralitic hornblende. The felspars are patchily reduced in basicity.

Veins in the mass may be described as basic granophyre (21540). They consist of a few large crystals of albitized labradorite in a finer-textured mass of less basic plagioclase, recrystallized hypidiomorphic augite, biotite, large plates of alkali-felspar of late consolidation, and an ultimate residue of alkali-felspar and quartz in coarse graphic intergrowth. The most acid portions are rich in large crystals of apatite.

A specimen collected from the white-weathering gabbro of the banded zone (p. 330) is gabbroic in texture (22628). It consists of albitized labradorite, augite which has been attacked with the development of scales of biotite and peripheral fibrous green hornblende, little nests of actinolite needles and biotite in association with alkali-felspar or quartz, and large irregular grains of magnetite. The finer-grained fluxion biotite-gabbro of the banded zone is subgranulitic in texture (22627), consisting of hypidiomorphic schillered augite, abundant irregular grains of magnetite, brown hornblende, plates of biotite, and prisms of moderately basic plagioclase. The hornblende and biotite occur sparingly and usually in association with the iron-ore.

The abnormal character of the mass of quartz-biotite-gabbro on the outer side of the banded zone is evident in specimens collected (21475). Much of the mass is strongly acidified (22254), and the amount of interstitial granophyric matter is considerable. In some parts of a thin section an original doleritic texture can still be distinguished; but the augite has been altered, biotite and hornblende developed, and basic felspars albitized, resorbed, and regrown with more acid peripheries that, like the graphic interstitial matter, are rich in apatite.

The interesting apophysis of the Fluxion Biotite-gabbro (K), which stretches out into the Great Eucrite and which has been referred to in detail above (p. 331), has a fine-textured sharp margin against the Great Eucrite. The junction of the two rocks can be examined in the area of a thin section. The marginal portion of the Sìthean Mòr mass (22252) is found to consist of an open mesh of small elongated crystals of oligoclase-andesine felspar with a fine granulitic matrix of augite, hypersthene, oligoclase-andesine, and magnetite. It includes a few small porphyritic crystals of a more basic plagioclase edged with oligoclase, and has ill-defined clots of coarsely crystallized material in which hypersthene is the more abundant pyroxene, and in which sporadic biotite has been developed. The turbid, schillerized, nature of the porphyritic felspars, and the pronounced granulitic texture of the rock as a whole, clearly indicate that the mass has been subjected to an elevated temperature since it assumed the solid state. As Mr. Richey suggests, this granulitization has probably been produced in the chilled edge of the intrusion (K) by reheating consequent on a fresh influx of magma from the same source.

The Eucrite (E) at the junction shows signs of crushing which are absent from the fine-grained rock in contact with it, but this crushing has been followed by a granulitization of the broken-down material. The basic felspars are intensely albitized both marginally and by veins of soda-felspar that traverse them in all directions. This intense albitization is undoubtedly connected with the later intrusion. Augite has passed over to uralitic hornblende, and there has been a small development of biotite.

At the actual contact, there has been a certain amount of give and take between the two rocks involved. On the Eucrite side there has formed a narrow zone of somewhat coarsely crystalline rhombic pyroxene and biotite with a recrystallized felspar of moderately acid composition. The rhombic pyroxene is pseudomorphed by fibrous hornblende, as also is the olivine occurring in the eucrite. This amphibolitization is presumably part of the process of thermal alteration to which both rocks have been subjected. The interior of this apophysal mass (22253) has already been referred to as having a coarser texture than its edge (p. 331). It is a somewhat fine-grained olivine-gabbro that has been considerably modified. Its structure is ophitic, but the augite has gone over in part to uralitic hornblende, while biotite has developed in association with it and with the small pseudomorphs after olivine. The original felspars have been albitized to some extent, and quartz and alkali-felspar charged with apatite occur interstitially. H.H.T.

(L) FLUXION BIOTITE-GABBRO OF GLENDRIAN

The almost complete ring-ridge formed of this intrusion is one of the striking features of the Achnaha district (*see* Pl. VI). The rock-type is similar to that forming the main portion of the Sìthean Mòr intrusion, except that small equi-dimensional crystals of magnetite appear to be more plentiful. In containing magnetite it differs from the adjoining coarse-textured Quartz-biotite-gabbros (J and J′) in which the iron-ore occurs as ilmenite in large crystals with two obliquely crossing cleavages. In the hand-specimen no two rocks could be more unlike, though in the field their line of separation is sometimes difficult to determine. Small masses of the coarse-textured gabbro are enclosed by the Fluxion Biotite-gabbro as, for example, near the outer southern margin of the intrusion, east of an old track that leads to Glendrian from the Achnaha road. Their mode of occurrence suggests that they are xenoliths. At other points, elongate inclusions of the same rock are also found, as, for example, 200 yds. east of Achnaha, and again three quarters of a mile north-east of this small village, between a basic north-west dyke and a stream. At the latter locality the elongate mass can be traced from where it ends against alluvium for 100 yds. uphill, parallel to the outer margin of the Fluxion Biotite-gabbro. These masses are probably portions of the walls caught up by the intruding magma. They furnish the only direct evidence that the Fluxion Biotite-gabbro is later than the Quartz-biotite-gabbros.

Sharp contacts between the Fluxion Biotite-gabbro and Quartz-biotite-gabbro outside it are exposed, on the south margin, along a scarp overlooking the Kilchoan-Achnaha road (Fig. 46, p. 323). At the contacts both rocks are quite unchilled and give no indications of their relative ages. The plane of junction at one contact is vertical, while at another it is inclined steeply inwards towards the Achnaha Centre (3).

The distinctness of the Fluxion Biotite-gabbro on its inner side from the coarse Quartz-biotite-gabbro (J′) is most evident where their junction has been mapped across a stream 500 yds. south-west of Glendrian farmhouse. In a steep scar forming the right bank, the Quartz-biotite-gabbro can be followed in exposures to within a few yards of where the Fluxion Biotite-gabbro outcrops. The actual contact of the two rocks is not seen. J.E.R.

Petrology (Anal. I, Table V, p. 89).—The Fluxion Biotite-gabbro of Glendrian is a basic gabbro more than usually rich in titaniferous iron-ore. All the specimens collected show an abundance of titaniferous magnetite more or less uniformly distributed throughout the rock in the form of irregular equidimensional grains and patches. As in the case of most other fluxion gabbros, such as that of Faskadale (p. 290), there are abundant signs of modification by an acid magma.

The analysed specimen (21249), which may be regarded as typical of the mass, is a moderately fine-grained dark rock in which the fluxion structure is brought out by the parallel arrangement of closely packed lustrous plates of felspar, which measure up to a quarter of an inch along their edges (21488–9). The fluxion structure is most clearly seen when the plates are viewed edge-on, and both in the field and in thin section it may be lost sight of if the rock be viewed normally to the larger tabular faces of the felspar crystals. Apart from this fluxion structure, the chief peculiarity of the mass is its high percentage of iron and titanium, constituents that find expression in an abundance of titano-magnetite and impart to the rock strong magnetic properties. On account of the abnormal segregation of iron-ore the mass is one of the most basic encountered in Ardnamurchan. It does not fit in with the normal differentiates of the Porphyritic Central Magma-Types, but shows a close similarity in composition to rocks leading towards the ilmenite-norites, and would find a place amongst such iron-ore rich bodies as those of the Ekersund-Soggendal district of Norway. Chemically its relations appear to be with the basic members of the Tonalite-Quartz-monzonite Series, and for this reason its unmodified character is suspect.

As mentioned above (p. 334), it is not uncommon to encounter large included masses of normal gabbroid material, which are quite unmodified. These Mr. Richey regards as of xenolithic origin, and microscopic evidence supports his view. One such mass from the eastern portion of the Fluxion Biotite-gabbro's outcrop (21806) is eucritic, very similar to the Great Eucrite (E) in type. It is free from iron-ore, rich in fresh olivine, and has basic labradorite as the dominant felspar.

The Fluxion Biotite-gabbro consists generally of large fluxionally arranged plates of intensely zoned and albitized basic labradorite, much augite frequently fringed with uralitic hornblende, and abundant titano-magnetite that occurs chiefly in association with the augite. Occasionally, the felspars are unzoned and appear to have escaped any serious albitization. In such cases, they have an optically negative sign and are of bytownite composition (21489). Where an excess of acid material shows itself in the rock as interstitial alkali-felspar and quartz in micrographic intergrowth, and in the crystallization of residual perthitic alkali-felspar, albitization of the basic felspars is the rule (21808). Also, the augite, in addition to exhibiting the usual deschillerization, may be largely converted into hornblende (21490). Biotite is developed, in such cases, both in the augite (21807) and in association with the iron-ore (21491). That olivine was an occasional constituent of the gabbro is inferred from pseudomorphs in chlorite and fibrous hornblende. A rhombic pyroxene, also, appears to have been present, as judged by certain pseudomorphs. It apparently occurred as a product of acidification, either as isolated crystals or replacing augite, with which it exhibits intimate relations (21491). When fresh the rhombic pyroxene is a highly pleochroic variety referable to hypersthene.

Apatite has undergone a concentration in the acid portions of the rock, similar to that observed in the tonalitic and quartz-monzonitic masses, and forms crystals nearly 2 mm. in length (21249, 21808).

There is little doubt that this Fluxion Gabbro owes many of its somewhat unusual physical and mineralogical characters to the intervention of an acid magma. It is difficult to say to what extent the rock-mass is to be regarded as of hybrid nature, but that it was in a modified condition before intrusion appears to be more than probable.

H.H.T.

(M) TONALITE

The Tonalite is in plan an oval-shaped mass, the longer axis of which is directed east-north-east, in conformity with other ring-dykes of Centre 3. Its margin has, however, many minor irregularities, as may be seen where it makes contact with the gabbros outside it, along a scarp that borders the road a quarter of a mile south-east of Achnaha. The striking difference in composition between the Tonalite and the surrounding gabbros enables its margin to be accurately traced.

The rock is everywhere of the same general type, with conspicuous biotite set in a greyish felspathic ground-mass, the dominant felspar being lath-shaped plagioclase. The rock varies in grain from place to place, though medium textures are most usual. Between an elongate screen-like mass of Quartz-biotite-gabbro (J″) and the outer wall, fine-grained types are chiefly met with, while at a point north-west of the western end of this screen the rock is unusually coarse.

Along its outer margin the Tonalite becomes much finer grained and at the same time more acid in composition. A gradual passage outwards from typical tonalite to this more acid margin can be established on the north-west and northern sides of the mass. The fineness of texture is a result of chilling, and not due to the change in composition, for on the north side the acid marginal type becomes finer grained close to the margin than it is farther away. The exposures concerned are along the eastern arm of a stream-loop which the junction crosses. In rock-type this acid margin is quartz-monzonite. Reference may be directed to Chap. XV, p. 209, where the significance of such acid margins is discussed.

The screen-like mass of Quartz-biotite-gabbro (J″), enclosed in the south-eastern part of the Tonalite, is seen at one point in contact with the Tonalite, which is chilled against it. This contact is located on the south side of the gabbro-screen, midway between two north-westerly hollows that cross the west part of the mass, and mark the course of two basic dykes. The western half of the gabbro is composed of a fine-grained type, and the eastern half of extremely coarse pegmatite-like gabbro. No contacts could be found between these two rocks owing to lack of exposure, but they may well be separate intrusions. Both may be classed as quartz-biotite-gabbro, though the more easterly rock is certainly more acid and must approach tonalite in bulk composition. Fluxion biotite-gabbro is a third rock-variety found in the screen, and forms its narrow south-western end.

The quartz-biotite-gabbro and fluxion biotite-gabbro of the screen correspond in position to similar gabbros, (J′) and (L), that form the opposite, outer wall of the Tonalite. They are evidence of the slightly transgressive nature of the Tonalite mass relatively to other ring-dykes, as is further brought out by the mapping of the Glendrian Ring-dyke (L). This intrusion, otherwise a complete ring, is broken through by the Tonalite for a short distance on its south-west side.

Acid veins traverse the gabbro walls of the Tonalite, and are abundant alongside the Achnaha road, a quarter of a mile south-east of Achnaha. They were classed as granophyre in the field. They have not been examined microscopically, but are of interest as being the acid expression of the Tonalite magma.

An example of hybridization *in situ* is well seen at the south-west termination of the gabbro-screen described above. There, xenoliths of the gabbro are contained in the Tonalite, and may be observed in all stages of dissolution. Patches of basified-looking tonalite probably represent completely digested xenolithic material. It may be remarked that no other instance of such hybridization was noted within the Tonalite.

J.E.R.

PETROLOGY OF THE TONALITE

(Anal. II, Table V, p. 89)

The Tonalite, with its related central intrusion of quartz-monzonitic type, is of especial interest, not only because it is one of the largest masses of this character met with in the Tertiary Province, but because it exhibits peculiarities of petrogenetic importance which point more or less conclusively to a hybrid origin.

In its most homogeneous and most normal occurrence, such as to the north and north-east of the Quartz-monzonite, it is a moderately fine-grained holocrystalline rock of grey-green colour, in which felspar and elongated crystals of hornblende occur in about equal proportions. Elongated much-twinned plagioclase felspars, up to a quarter of an inch in length, are common, but the bulk of the felspar is of later formation and occurs as a matrix to the other constituents. This later felspar frequently has a decided pink tinge.

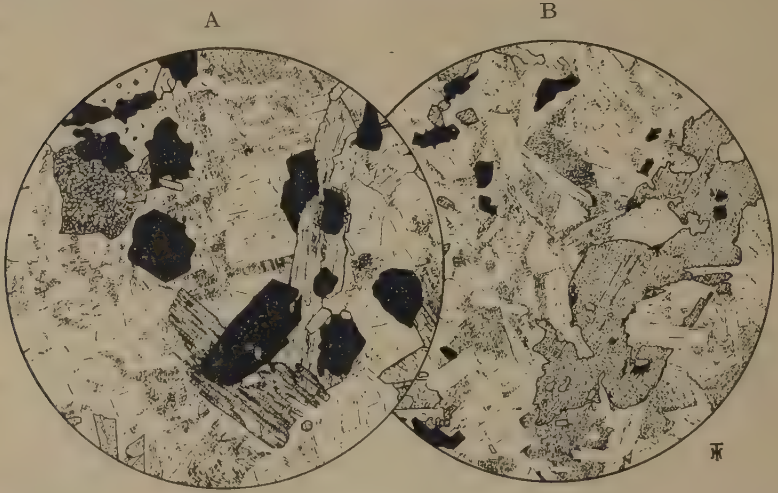

Fig. 48.—*Tonalite and Quartz-monzonite.*

A. (21248)×20. *Tonalite. Biotite, hornblende, and augite with plagioclase felspar, perthite, and quartz. Magnetite and apatite are abundant accessories. The alkali-felspar is mainly turbid.*

B. (21247)×20. *Quartz-monzonite. The section shows a large plate of biotite, with subordinate augite, abundant elongate crystals of oligoclase-andesine felspar, in an apatite-rich turbid base of albite-perthite and quartz.*

Biotite is usually subordinate to hornblende but occurs in small deep-brown flakes.

The structure of the rock is granitic, and the constituents, as proved by microscopic examination, are plagioclase felspar, hornblende, biotite, augite, perthite, and quartz; with some apatite, magnetite, and sphene (21248).

The plagioclase occurs as much fissured, resorbed, and intensely albitized crystals of labradorite, zoned with oligoclase and fringed with perthitic orthoclase (21468). Oligoclase may also build elongated lath-shaped crystals. The biotite is a deep-brown variety that occurs in moderately large ragged plates, and is frequently chloritized. The hornblende is generally of a greenish-brown colour with moderate pleochroism (22260), and together with biotite forms about half to a third of the rock. Perthitic orthoclase, often intergrown with quartz, occurs as large turbid shapeless crystals that envelop all the other constituents (21470). Augite is not particularly abundant in the more widely distributed type, but becomes a more important constituent in some portions of the mass, particularly to the south-east of the screen (p. 337). When present, it occurs as fairly large ill-formed almost colourless individuals that generally exhibit a partial pseudomorphosis to hornblende, giving a mottled appearance to the crystals as a whole (21468). Apatite in the coarser tonalitic rocks occurs as extremely large and abundant crystals. Such crystals often exceed a millimetre in length, which is far in excess of the dimensions of apatite as encountered in any of the normal rocks of Ardnamurchan. There has evidently been a strong concentration of phosphoric acid and volatile constituents in the more alkaline and siliceous portions of the magma; for apatite seldom occurs in the basic felspars, but is almost restricted to the acid plagioclase and perthite, with quite subordinate amounts carried by the ferromagnesian constituents, more especially by the biotite and hornblende. Magnetite occurs sparingly as fairly large irregularly bounded masses, most frequently in association with augite or hornblende. Sphene is uncommon, and is chiefly encountered in granular form associated with chloritized biotite.

To the south of the monzonitic mass, the tonalite in its central portions is of the same type as that described above, except perhaps that augite is a little more abundant (21541), and that here and there the rock becomes almost pegmatitic in character. In these pegmatitic portions (21549) the rock is coarser in texture, biotite is more abundant and occurs in large plates, and the perthitic felspar forms irregularly bounded pink patches of more than half an inch across. Commonly the perthite is graphically intergrown with quartz.

Between the screen of biotite-gabbro and the eastern margin of the mass, the usual type of tonalite is encountered (21469), but generally the rock is somewhat different in both aspect and composition. The main difference lies in its more augitic nature. In some instances, the normal structure of the tonalite is maintained while augite, partly recrystallized and partly xenocrystal, occurs with a fair amount of biotite and brownish-green hornblende (22257). In other cases, augite is the dominant ferromagnesian mineral, and biotite and hornblende though present become quite subordinate (22255). Such rocks have a microporphyritic structure imparted to them by numerous small resorbed and albitized labradorite felspars that are set in a somewhat granulitic matrix of small hypidiomorphic crystals of augite, stumpy crystals of oligoclase-andesine felspar, and irregular grains of magnetite. The general family resemblance of these and all other rocks in the tonalite and quartz-monzonite masses, however, lies chiefly in the occurrence of large crystals of greenish-brown hornblende, biotite, and patches of perthite, and in segregation of apatite. The effects of granulitization and hybridization of a basic rock are evident in this eastern portion of the tonalitic mass (21472, 21542).

Towards the outer margins the rock becomes finer in grain and more acid in composition. It is noticeable that biotite ultimately becomes the dominant ferromagnesian constituent, and with a certain amount of augite gives to the mass a quartz-monzonitic or mica-felsite character. Towards the western and northern margins the tonalite retains its dominantly hornblendic nature for some distance (22260, 21467), but then passes gradually into a much paler rock composed essentially of lath-shaped crystals of turbid oligoclase-albite, perthitic orthoclase, and graphic quartz, with biotite and iron-ore (21474, 22258). In extreme cases of acidification the ferromagnesian minerals fail altogether (22259), but in others biotite is abundant as small ragged flakes. In the latter cases, the rock consists mainly of biotite, short prisms of oligoclase, and granules of magnetite in a base of large shapeless crystals of perthite, with a certain amount of quartz. Augite may occur occasionally as long partly uralitized crystals (21539). In these acid rocks it may be remarked that there is no strong concentration of apatite such as is a feature of the more definitely tonalitic mass.

The xenocrystal nature of the Tonalite, the presence of hornblende and biotite of late generation, and the lateral passage into rocks of quartz-monzonitic type along its peculiar acid margin, are features that all point to this intrusion being a gabbro-granophyre hybrid. It is, however, equally certain that the hybridization was an accomplished fact before the intrusion of the mass into its present position, as in the case of the marscoite masses of Skye; but, instead of the acidification of a basic magma, as in the Skye occurrences, we are presumably dealing here with the basification of an acid magma.

The Quartz-biotite-gabbro Screen (J″).—This screen-like mass within the tonalite is definitely of gabbro-origin. It has, however, suffered greatly at the hands of an invading acid magma, and like other biotite-gabbros shows unmistakably the effects of hybridization. In fact, the changes that have taken place are just such, given full expression, as would lead to the formation of tonalitic and quartz-monzonitic types. For instance, a moderately coarse augitic gabbro (21543) that forms the western part of the screen shows intense albitization of its basic felspar. Its augite has been locally deschillerized with the production of small scales of biotite. Further, introduced alkaline and siliceous magma has solidified as microperthitic felspar and quartz between the albitized gabbro-felspars, and has controlled the formation of biotite. Apatite in some of these modified gabbros forms large and abundant crystals (21257). Acid portions of the screen might be described as perthite-granophyre, as the rock is composed almost entirely of large areas of cryptoperthite graphically intergrown with quartz (22458). H.H.T.

(N) QUARTZ-MONZONITE

As a rock the Quartz-monzonite may be distinguished from the surrounding Tonalite by the following criteria. Biotite is more plentiful and in larger crystals than in the Tonalite. The felspathic portion of the rock is finer textured, and it is possible to distinguish in the hand-specimen the darker plagioclase from a lighter and compact orthoclase-quartz portion. The latter constitutes about a half to a third of the rock.

The little central mass of Quartz-monzonite is separated as a distinct intrusion from the Tonalite, on account of an intrusive junction seen on its north-west side. There, a sharp contact between the two rocks exists, and while the Tonalite does not change in grain, the Quartz-monzonite is markedly finer textured for an inch or so away. The Quartz-monzonite is situated at the actual centre of the Interior Complex, and is the latest intrusion of the whole ring-dyke suite. J.E.R.

Petrology (Anal. III, Table V, p. 89). — This mass, which on mineralogical and structural grounds is best described as a quartz-monzonite, is of a medium-grey fairly compact rock in which small porphyritic felspars about 4 or 5 mm. in length, and more or less evenly distributed biotite in plates of somewhat larger dimensions, are the conspicuous minerals (21548, 21471, 21247).

Microscopically (Fig. 48) the rock is seen to be holocrystalline; it consists of a few moderately large crystals of labradorite, strongly zoned to oligoclase, an abundance of small elongate crystals of oligoclase-andesine, large ragged plates of biotite, scattered small hypidiomorphic crystals of an almost colourless to pale-green augite and magnetite, in an apatite-rich base composed of albite-perthite and quartz.

The amount of labradorite is small, for it exists only as somewhat infrequent centres to some of the larger plagioclase-crystals that are deeply zoned with less basic varieties, and which usually have oligoclase peripheries.

The biotite is a deep-brown variety. It frequently encloses crystals and patches of oligoclase felspar, but the perthitic alkali-felspar and quartz are moulded upon it. It is more or less devoid of other inclusions, except occasional apatite, and does not exhibit pleochroic halos. When decomposed it passes into chlorite with, sometimes, the separation of granular sphene.

The augite is scattered indiscriminately throughout the rock, generally as small ill-formed crystals but occasionally as prisms and stumpy individuals with fairly good crystal-outlines. It has the wide extinction and moderately large axial angle of a normal aluminous augite, but its colour is similar to that of the recrystallized augite of the modified gabbros that have been frequently referred to in earlier pages.

The perthitic felspar builds the largest individual crystals in the rock, and embraces all the other constituents. It is usually intensely turbid and in it, and in the oligoclase, is concentrated the bulk of the apatite. As in most other Ardnamurchan rocks of this nature, it is clear that the constituents of apatite are concentrated in the alkaline and more siliceous portions of the magma, and the period of crystallization of the mineral is mainly concurrent with that of biotite and acid plagioclase, including the albite-perthite. It is seldom encountered in the quartz except as crystals projecting from neighbouring felspars.

This monzonitic mass is genetically related to the tonalite described above; and chemically, as will be seen from the analyses (Table V, p. 89), the two rocks have many points in common. It is not surprising, therefore, to find represented at the margin of the tonalitic mass, rock of quartz-monzonitic character; we may, in fact, regard this monzonitic mass as a further stage in the hybridization of a eucritic rock, or magma, with a magma of definitely siliceous and alkaline composition, rich in volatile constituents. H.H.T.

CHAPTER XXII

TERTIARY DYKES, ARDNAMURCHAN AND NORTH-WEST MULL

BASIC dykes are widely distributed throughout the British Tertiary igneous province, and extend far beyond the limits of the plateau lavas. They are found from the Outer Hebrides, where they traverse the Lewisian gneiss, to as far south at least as North Wales and the English Midlands, where the Trias is the youngest formation cut by them. They are especially prevalent in the neighbourhood of the plutonic centres where they traverse other Tertiary igneous rocks, as well as Cretaceous, Jurassic, and Triassic sediments. Their identification as Tertiary in areas of Palæozoic and pre-Cambrian rocks depends in large measure on the peculiarity of their rock-types coupled with the fact that the prevalent direction of Tertiary dykes in Britain is north-west.

The detailed mapping of the British Tertiary dykes has demonstrated that they are concentrated in north-westerly directed swarms, and that each swarm is coincident with one of the plutonic complexes. Further, the number and aggregate thickness of the dykes composing a swarm increases markedly in the vicinity of the plutonic complex concerned. These remarkable features of dyke-distribution seem to have been first clearly recognized by Mr. H. B. Maufe[1] in the case of the Mull Swarm, largely on account of his work on the mainland south-east of Mull (Sheet 36). The localization of dyke-swarms at plutonic centres was attributed by Mr. E. B. Bailey[2] to the local weakening of the crust where traversed by pipes filled to a large extent with unconsolidated magma. In the British Tertiary province, well-marked dyke-swarms are associated with the central intrusive districts of Skye, Rum, Mull, and Arran in Scotland, and with the Mourne and Carlingford districts in Ireland (*see* Fig. 4, p. 53).

In Ardnamurchan, the dykes are considered to be in part referable to the Mull Swarm, in part to belong to the Ardnamurchan district itself. The majority are basic in composition, but a number of acid dykes have also been mapped. They usually have a north-westerly trend, though many dykes, both basic and acid, follow other directions. In North-west Mull, only basic north-west dykes are met with, and are a continuation of the Mull Swarm (Fig. 49).

In both North-west Mull and Ardnamurchan, the dykes are, with rare exceptions, single individuals. In Ardnamurchan, only a few instances of double basic dykes, and only two of composite habit, have been noted. In this respect these districts differ from Central Skye and Central Mull, where double and multiple dykes are frequent.

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[1] *Cf.* E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 10.

[2] 'The Cauldron-Subsidence of Glen Coe,' *Quart. Journ. Geol. Soc.*, vol. lxv., 1909, pp. 674–675.

The dykes of North-west Mull, as described by Mr. G. V. Wilson in the 'Tertiary Mull Memoir' (p. 358), are in large measure re-

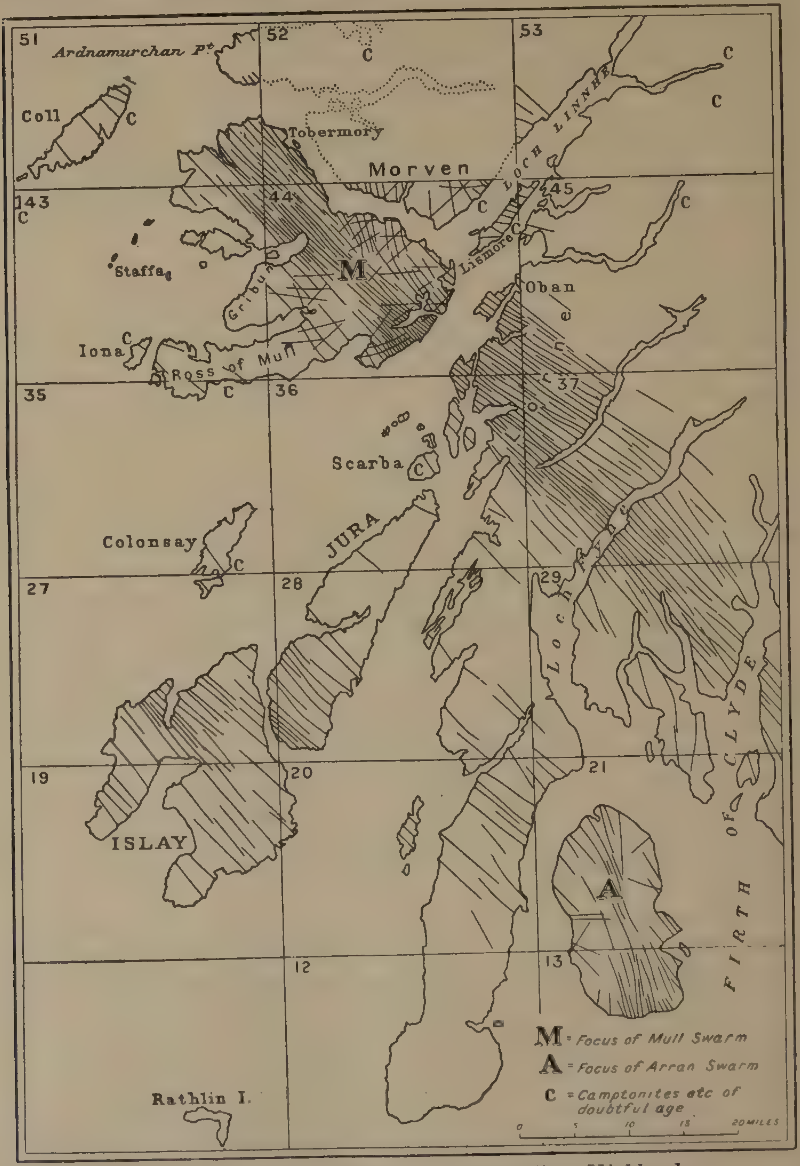
51
52
53
Ardnamurchan Pt.
Coll
C
Tobermory
Morven
LOCH LINNHE
143
44
45
Staffa
Gribun
M
Lismore
Oban
Iona
Ross of Mull
35
36
37
Scarba
Colonsay
JURA
27
28
29
Loch Fyne
19
20
21
ISLAY
FIRTH OF CLYDE
A
12
13
Rathlin I.
M = Focus of Mull Swarm
A = Focus of Arran Swarm
C = Camptonites etc of doubtful age
0
5
10
15
20 MILES

FIG. 49.—*Tertiary Dykes of the South-West Highlands.*
Only about one dyke in every ten or fifteen in shown.
Quoted from 'Tertiary Mull Memoir,' 1924, *Fig.* 60, *p.* 357.

sponsible for a lineated scenery in the district eastwards of Dervaig. This belt of country is characterized by a north-westward direction

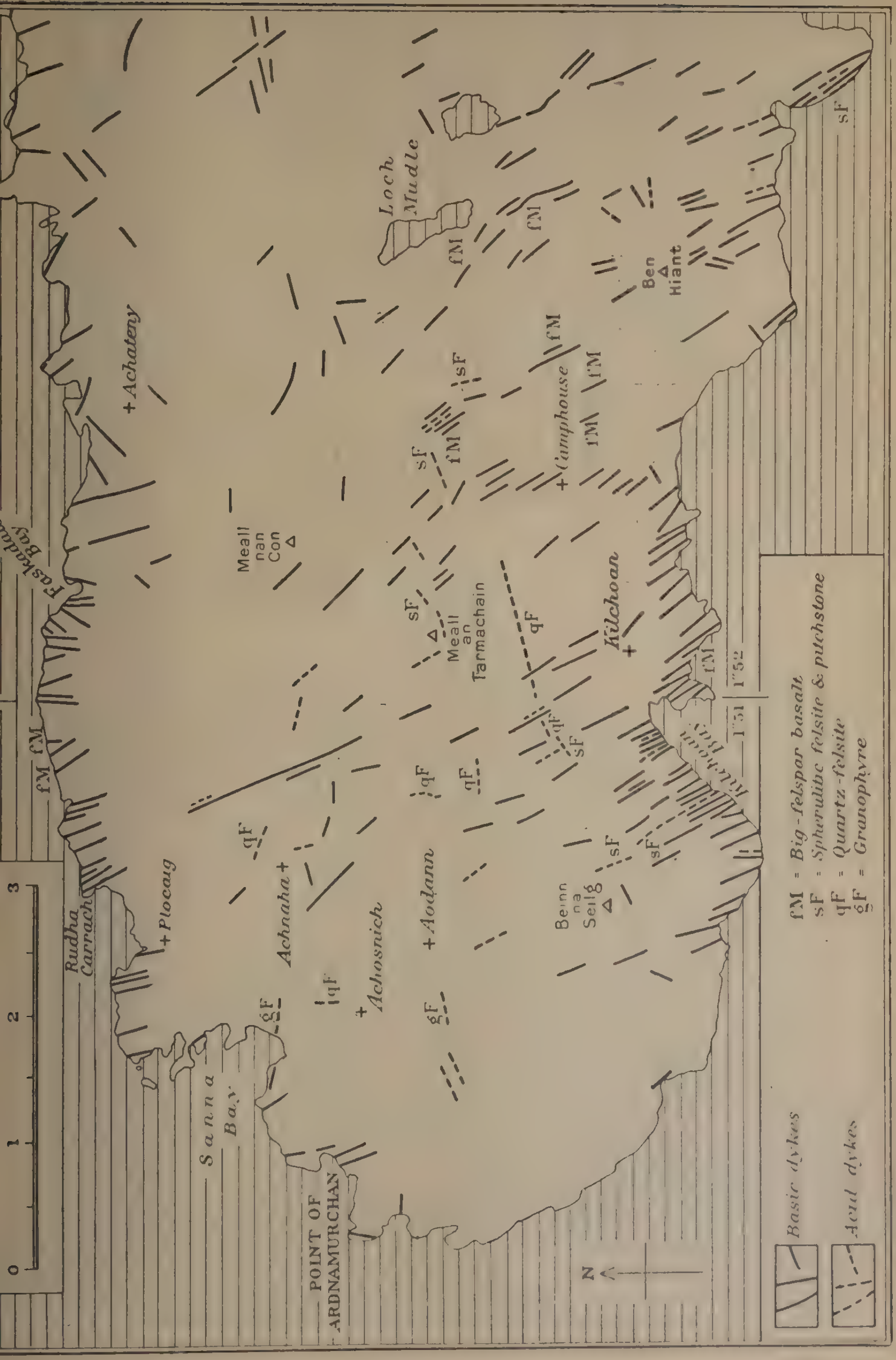
Loch Mudle
Ben Hiant
Camphouse
Kilchoan
Meall nan Con
Meall an Tarmachain
Achateny
Fascadale
Rudha Carrach
Plocaig
Achnaha
Achosnich
Aodann
Beinn na Seilg
Sanna Bay
POINT OF ARDNAMURCHAN
N
0
1
2
3
1"31
1"52
fM
sF
qF
gF
Basic dykes
Acid dykes
fM = Big-felspar basalt
sF = Spherulitic felsite & pitchstone
qF = Quartz-felsite
gF = Granophyre

FIG. 50.—Map of Tertiary Dykes, Ardnamurchan.

of ridge and hollow, erosion having been controlled to a very large extent by dykes, and to a lesser degree by parallel crush-lines. In Ardnamurchan, dykes play a small part in guiding erosion, but north-westerly or northerly crush-lines, sometimes accompanied by dykes, have often determined the positions of streams and valleys, more especially in the western part of the peninsula.

TABLE VIII

DATA CONCERNING MULL DYKE-SWARM

Locality.	Breadth of Swarm or Portion of Swarm Examined.	Number of Dykes.	Total Aggregate Thickness of Dykes.	Average Individual Thickness.	Average Number per mile.	Average Aggregate Thickness per mile.	Amount of Crustal Stretch due to Dyke-Intrusion.
S.-Central * Mull.	12½ mls.	375	2504 ft.	5·8 ft.	30	200 ft.	1 in 25
N.-Central * Mull.	1¼ mls.	142	817 ft.	5·8 ft.	114	654 ft.	1 in 8
North-west Mull.	5 mls.	62	480 ft.	7·7 ft.	12	96 ft.	1 in 55
South-west Ardnamurchan.	1½ mls.	36	272 ft.	7·5 ft.	24	180 ft.	1 in 30

* Data from 'Tertiary Mull Memoir,' p. 360.

DISTRIBUTION

As mentioned above, the Mull Swarm traverses North-west Mull, and a portion of it may be presumed to extend to the western part of the Ardnamurchan peninsula. On Table VIII, the numbers and aggregate thicknesses of dykes belonging to the swarm are shown for Central and North-west Mull and for the south-west part of Ardnamurchan. It will be seen that these values decrease greatly in North-west Mull as compared with Central Mull, but that in south-western Ardnamurchan there is a renewed increase. While it must be remembered that we are only dealing here with a portion of the Mull Swarm, the increase seems too large to be merely a matter of chance; it is certainly in part due to the occurrence of a few local acid dykes, but may be in part attributed to the presence of basic dykes belonging to an Ardnamurchan suite. In the more easterly parts of the Ardnamurchan area here described, a number of north-west dykes have been mapped which lie too far to the east to be referred to the Mull Swarm. Yet farther east, beyond the eastern boundary of the area, Tertiary dykes become very scarce. There thus seems to be a local concentration of dykes belonging to the intrusive district of Ardnamurchan, though the dykes are nowhere as numerous as in the case of Central Mull.

As will be seen on Fig. 50, a number of the Ardnamurchan dykes on the northern coast between Rudha Groulin and Faskadale Bay trend west of north and north. Similar deviations from the usual north-west direction are also met with in the northern parts of other intrusive districts, northwards of Central Mull, Rum, Central Skye, and Arran, as shown on Fig. 4, p. 53. In Ardnamurchan there are also a number of what may be termed transverse dykes, of both basic and acid composition, which run north-east or east-north-east at approximately right angles to the prevailing north-west or north-north-west directions. Since the transverse dykes are found across the whole breadth of the peninsula from the northern coast near Achateny southwards to the Ben Hiant district, they cannot well belong to a radial set such as is found in Rum [1] and in the Cuillins of Skye.[2]

Age Relations

In North-west Mull basic dykes are frequently seen traversing the coastal cliffs that are formed of the plateau lavas. No instance has been noted there or elsewhere in the Inner Hebrides of a dyke of earlier date than any of the lavas exposed, and the majority at least of the dykes are presumably later than the plateau lava period. They were probably injected at various subsequent times, and do not belong to one epoch of intrusion. Such is certainly the case in Central Mull, where individual dykes can be dated relatively to various other intrusive rocks.[3] In Ardnamurchan, the dykes, both basic and acid, are also of various dates, as will appear from the following instances, in which it has been possible to determine age relations in regard to other intrusions.

An east–west composite dyke with central portion of bostonitic granophyre (22259), cutting basalt lavas that form the eastern wall of the North-east Vent of Ben Hiant, is truncated at the vent-margin, and is clearly earlier than the vent (Fig. 11, p. 123). Two trachyte dykes (26675) may here be mentioned which traverse the brecciated lava-wall of the same vent on the north-east side of Ben Hiant, and which probably belong to the Ben Hiant vent-period.

A number of dykes of basalt with large felspar phenocrysts are also to be assigned to this period, since they are identical in rock-type with blocks in the Ben Hiant agglomerates (p. 136). These dykes (lettered fM on the Memoir-map and on Fig. 50) are sparsely distributed, and all trend north-west with the exception of one individual directed north and south on the northern coast, a mile west of Faskadale Bay. An example on the shore, south of Kilchoan, 200 yds. east of Mingary Pier (Fig. 23, p. 174), and two others on the northern coast between Rudha Carrach and Faskadale Bay one of which is the north–south dyke just mentioned, are cut by the Outer Cone-sheets of Centre 2. Sheet-like or elongate masses of the same rock-type are also met with. A sheet cut by the Outer Cone-sheets has been mapped inland from the northern coast south of the more easterly of the two dykes quoted above from this district. Two elongate masses, perhaps short thick dykes, occur one to the south of the summit of Beinn nan Losgann, the other north of Loch Mudle.

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[1] A. Harker, 'The Geology of the Small Isles of Inverness-shire,' Explanation Sheet 60, *Mem. Geol. Surv.*, 1908, Pl. III, p. 144.

[2] A. Harker, 'The Tertiary Igneous Rocks of Skye,' *Mem. Geol. Surv.*, 1904, p. 364.

[3] E. B. Bailey, W. B. Wright, and J. E. Richey *in* 'Tertiary Mull Memoir,' 1924, pp. 360–362.

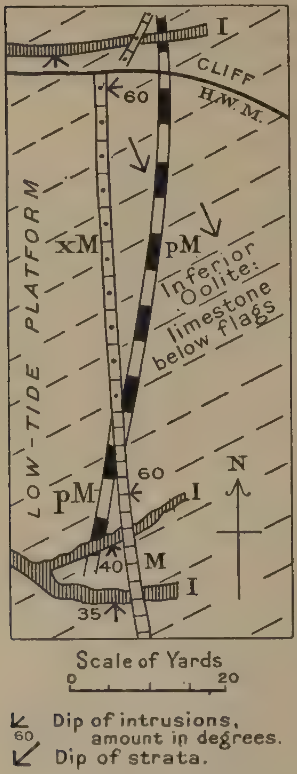
I
CLIFF
H.W.M.
60
xM
pM
Inferior Oolite: limestone below flags
LOW-TIDE PLATFORM
N
60
pM
I
40
M
I
35
Scale of Yards
0
20
60 Dip of intrusions, amount in degrees.
Dip of strata.

FIG. 51.—*Map showing relations of dykes and cone-sheets, on shore west of Sròn Bheag.*

pM, *4-ft. porphyritic basalt dyke.* I, *cone-sheets of quartz-dolerite* (*Talaidh type*). M, *5-ft. non-porphyritic dyke of quartz-dolerite* (*Talaidh type*). xM, *xenolithic portion of* M. H.W.M., *high-water mark.*

Numerous instances of dykes of the usual basic types cut by cone-sheets of the Outer Set of Centre 2 have been noted. Many of these are shown on the Figures on pp. 34, 174, and 177. In some cases it is found that the same dyke cuts some cone-sheets and is cut by others, and thus demonstrably belongs to the period of injection of the Outer Cone-sheets (*see* p. 176). Two examples of dykes in continuity with a cone-sheet in one case and with sills in the other have been examined. On the west shore of Kilchoan Bay, two thirds of a mile south-west of the Landing Jetty, a north-west porphyritic basic dyke is in visible continuity with a cone-sheet, which is cut by a pitchstone dyke (Fig. 3, p. 34). Again, on the east side of Mingary Castle, two basic sills are connected by a short dyke (Fig. 25, p. 177). In the latter case it would seem as if the sills acted as feeders for the dyke.

Various acid dykes cut by the Outer Cone-sheets have also been mapped. Instances are a north-west dyke of bostonite, 7 ft. in width, the more northerly of the acid dykes mapped on the west shore of Kilchoan Bay, and an unusually thick north-west composite dyke, west of Sròn Bheag, 80 ft. wide, with a central portion of felsite with fluxioned edges 27 ft. in width (Fig. 3, p. 34).

Interesting age relations between dykes and cone-sheets belonging to the Outer Set on the shore west of Sròn Bheag are illustrated in Fig. 51. A north-north-east porphyritic basalt dyke (lettered pM on Fig. 51) is cut by quartz-dolerite cone-sheets (I). Both the dyke and the cone-sheets are in turn traversed by a north–south non-porphyritic quartz-dolerite dyke (M), in part xenolithic (xM). Chilled margins in all cases mark the contacts of the younger against the older intrusions, except where the xenolithic portion of the north–south dyke is in contact with the porphyritic dyke. The contact at this point is seen as a sharp wavy line along which the north–south dyke is apparently unchilled.

The north–south dyke only contains xenoliths north of where it crosses the porphyritic dyke. The xenoliths appear in profusion just where the chilled margin of the north–south dyke against the porphyritic dyke gives place to the unchilled margin. They are equally abundant throughout the northern portion of the dyke, and occur even on the chilled margins. They are angular masses or fragments, usually narrow in comparison with their length which ranges up to 3 ft. Petrologically the xenoliths, though porphyritic (21834), do not closely resemble the material of the porphyritic dyke pM (21832). On the other hand, apart from their conspicuous felspar phenocrysts, they are quartz-dolerite of Talaidh type similar to the enclosing matrix. This matrix seems to be continuous with the dyke M (21833).

The xenoliths, notwithstanding their slight marginal corrosion, would seem from their arrangement to have originally fitted into one another. It is not unlikely that they originally constituted a dyke which failed to extend across the porphyritic dyke (pM) and which was subsequently brecciated and injected by the non-porphyritic magma (M) intruded along the same line of fissure, with little displacement of the brecciated material. No definite reason can, however, be advanced for the curiously local, unchilled contact of xM with pM.

Porphyritic xenoliths similar to those found in the xenolithic dyke above described have been noted in a cone-sheet about 150 yds. west of the xenolithic dyke. The occurrence suggests that there are cone-sheets of the same age as the xenolithic dyke, especially since the Talaidh type of quartz-dolerite, typical of the cone-sheets generally, is the rock-type of which the xenolithic dyke is composed.

It is, indeed, not improbable that many at least of the basic dykes of types similar to the Outer Cone-sheets were injected during this cone-sheet period, even in cases where they are seen to cut adjacent cone-sheets. A later date may, however, be assigned to a number of dykes composed of olivine-dolerite that traverse the Outer Cone-sheet Complex and are sometimes traceable for considerable distances.

The age relations between such comparatively late dykes traversing the cone-sheet area that surrounds the plutonic complex and the plutonic rocks themselves can rarely be determined. An instance is supplied by a north-west olivine-dolerite dyke, 24 ft. in width, which cuts the cone-sheet complex on the lower, western slopes of Glas Bheinn north of Kilchoan. The dyke has been traced close up to the margin of the Hypersthene-gabbro Ring-dyke (a), but does not penetrate the gabbro. Close to the gabbro the dyke is cut by acid veins such as are often seen to traverse the country rocks along the gabbro margin. The dyke itself is slightly contact altered as shown by a development of biotite in connexion with decomposed olivine (21431). This dyke is therefore considered to be earlier than the Hypersthene-gabbro.

Comparatively few dykes cut the ring-dykes themselves. The sparseness of such dykes in the western part of the Ardnamurchan peninsula is especially marked. Since this area lies directly astride the course of the Mull Swarm, it would seem as if the great majority of the dykes of this swarm must be earlier than the Ardnamurchan ring-dykes. On the other hand, failure of dykes to penetrate the plutonic masses does not necessarily imply that these masses are of later date. Suggestive evidence is afforded by certain dykes that are intruded along crush-lines in the country rocks bordering the plutonics. For example, midway between Sròn Bheag and Beinn nan Codhan, two crush-lines marked by stream-hollows are followed by dykes of olivine-dolerite. The crush-lines, but not the dykes, extend northwards to traverse the adjoining ring-dyke complex of Centre 2. It would seem as if the supply of magma available for dyke-intrusion was in some way cut off near to the margin of the ring-dyke complex. In this connexion it is perhaps noteworthy that the numerous crush-lines traversing the ring-dykes are in no known instance accompanied by dyke-intrusion. J.E.R.

PETROLOGY

Although the majority of the dykes that occur within the Ardnamurchan peninsula are of generally basic character, there is considerable variation both in texture and composition, while intermediate and acid types are by no means rare. It is noteworthy that dykes of plateau-basalt composition, although well represented among the north-westerly directed examples, are not so prevalent as might be expected, and that the greater number of the basic dykes appear to have a quartz-dolerite or tholeiitic composition. For purposes of description the various dykes will be considered under the following headings, and reference will be made where possible to the extension in time of each class :—Plateau Basalt Type, Porphyritic Central Type, Tholeiites and Quartz-dolerites, Intermediate and Sub-acid Dykes, Acid Dykes, and Composite Dykes :—

Dykes of Plateau Basalt Type.—As in Mull and other parts of the Tertiary Province there are a number of dykes that are directly comparable with the Plateau Basalt Lavas both as regards texture and composition, and are best described as being of Plateau Basalt Type. They are moderately fine-grained non-porphyritic, dark-grey to black crystalline rocks, characterized by fairly abundant olivine, an ophitic lilac-tinted titaniferous augite, lath-shaped zoned labradorite felspar of normal composition, fairly abundant titano-magnetite and apatite, and a variable amount of base that may be either glassy or analcitic. They are of all ages, and point to the availability of the normal plateau basalt magma at all stages of the igneous activity. One of these dykes (21473) in Ardnamurchan is of the latest demonstrable age, for it cuts the Tonalite of Centre 3. In composition it approaches the crinanites or analcite-dolerites, as it contains a fair amount of analcite in its base, together with many small flakes of deep-brown biotite. Where this alkaline mesostasis is brought into contact with the normal augite the pyroxene is edged with green aegirine-augite.

A 60-ft. dyke of similar type (24475) cuts the basalt lavas of Ardslignish. It is rich in fresh olivine and titaniferous augite, and has a little biotite developed in association with both olivine and iron-ore; apart from the fact that it is later than the plateau basalts there is no further evidence of its age.

A group of north-westerly dykes that cut the agglomerates and associated rocks in the neighbourhood of Rudha Carrach on the north coast are typical olivine-dolerites of plateau type (22424), with fresh olivine and ophitic highly coloured titaniferous augite. On the other side of the peninsula similar north-west dykes cut the older rocks in the neighbourhood of Kilchoan (21842).

A dyke of ophitic dolerite 36 ft. in thickness which cuts the older Mesozoic sediments on the west side of Kilchoan Bay is interesting on account of its local pegmatitic development and geodal character. The rock (22425) consists of large ophitic augites, pseudomorphs after olivine, and large leucoxenic crystals of ilmenite associated with felspars that show both albitization and silicification. The main peculiarity of the rock is the occurrence of large amygdaloidal patches and streaks of fine-grained acid material. The amygdaloids are occupied at their centres by highly birefringent colourless prehnite and lined with a mosaic of small interlocking crystals of albite-perthite (Fig. 52 B, p. 354). The prehnite of the central infilling carries near its outer boundary an abundance of small idiomorphic colourless garnets that measure up to 0·2 mm. in diameter, but are usually smaller. The rock is chloritized, and within the chlorite as well as in the serpentine-pseudomorphs occur strings of minute badly-formed garnets of pale pinkish-brown colour, as well as bunches of acicular actinolite. Garnet, however, is more particularly abundant in association with the prehnite. These patches within the dolerite recall the garnetiferous amygdales contained in some of the Mull lavas, for which a metamorphic origin has been claimed. It was found in Mull that the association of prehnite and garnet was consequent on the metamorphism of scolesite, etc., that frequently formed normal amygdaloidal infillings. As the doleritic portion of this dyke is in an unmetamorphosed condition, we must regard the peculiar mineral assemblage as belonging to the pegmatitic facies of the dyke.

Dykes of Porphyritic Central Type.—A group of conspicuously porphyritic basic dykes (lettered fM on Fig. 50), sparsely distributed, appears to be an early phase of dyke-intrusion in Ardnamurchan, as many examples are cut by the Outer Cone-sheets of Centre 2.

In general type these rocks are similar to those met with as blocks in the agglomerates, and as intrusions, in the Ben Hiant vent. They are linked together by the common feature of an abundance of porphyritic basic plagioclase felspar, individual crystals ranging from a few millimetres to 4 or 5 inches in length. These felspars show some range in composition although they seldom exhibit strong zoning; generally they consist of a basic labradorite or bytownite with a thin outer layer of oligoclase (21433), but are often extensively albitized (22426). The very large felspars from a somewhat narrow big-felspar basalt dyke exposed on the shore south of Kilchoan, 200 yds. east of Mingary Pier, proved to be a labradorite of more or less normal composition. They had a specific gravity of 2·71, were optically positive, and by the immersion method gave $\alpha = 1{\cdot}557$ and $\gamma = 1{\cdot}565$. Such values suggest a composition of approximately $Ab_{43}An_{57}$, a composition quite commonly assumed by porphyritic plagioclase in rocks of basaltic nature.

Both olivine and augite (24406) may occur as subordinate and relatively insignificant porphyritic individuals, but generally they are confined to the matrix. Olivine is seldom encountered in a fresh condition, and the augite, unlike that of the plateau basalts and dykes of plateau type, is a yellowish to greenish-brown variety. The matrix is somewhat variable in character. In some dykes it is basaltic with narrow laths of felspar, hypidiomorphic to granular augite, and fairly abundant magnetite (21832). In other examples, the matrix has the character of the olivine-tholeiites. It then consists of fairly abundant small olivines, lath-shaped felspar, and an augite that exhibits an ophitic structure frequently associated with a stellate grouping of the felspar-laths (21433, 22426).

On account of their age many of these dykes show the effect of thermal alteration, which usually takes the form of conversion of augite into uralitic hornblende and the development of minute scales of deep-brown biotite throughout the rock (22235).

Tholeiite and Quartz-dolerite Dykes.—A considerable number of the north-westerly dykes, as well as the majority of those which depart from the normal direction, are dolerites of somewhat different type to those which have a plateau basalt composition. They differ primarily in the colour of their augite, but they also develop an acid mesostasis of variable amount, and pass by insensible gradations through various types of quartz-dolerites and tholeiites. The change in composition is generally accompanied by a change in the type of crystallization. There is a gradual suppression of the coarse ophitic structure of the dolerites in favour of a more localized separation of augite, and a tendency for this mineral to assume a columnar habit. The dominant types represented among these dykes appear to be olivine-bearing quartz-dolerites, and tholeiites of Salen and Talaidh types.[1]

Of the more definitely doleritic and ophitic types some are of quite late intrusion, and cut members of the ring-dyke complex (22427–8). They have, however, an east and west, or west-north-westerly trend. They are dolerites with a tholeiitic type of crystallization, but are frequently much albitized and chloritized.

Olivine-bearing quartz-dolerites, comparable in type to those forming the Ben Hiant intrusion (p. 169), occur as dykes in the south and south-east of the peninsula. Many are of fairly early date, being cut by cone-sheets, and mainly of north-westerly direction (21431–2). Olivine was present as a porphyritic constituent, and the matrix is either doleritic or tholeiitic with the inclusion of some acid mesostasis. A dyke that cuts the craignurite sill of Mingary Castle is an olivine-bearing rock (22423), not quite so like the Ben Hiant type as some of the others, but obviously belonging to the same type of magma.

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[1] H. H. Thomas and E. B. Bailey *in* 'Tertiary Mull Memoir,' 1924, p. 370.

Closely related are the tholeiites of Salen type with their fairly prevalent olivine. One such dyke (22297), 10 ft. in width, and with a well-developed platy structure cuts the Ben Hiant intrusion in a north-westerly direction. This type is also represented amongst the early cone-sheets (24396).

The Talaidh type of tholeiite, so prevalent as cone-sheets, is also responsible for many dykes. One of these (21833), with a north and south direction, occurs on the shore west of Sròn Bheag (Fig. 51). It contains the usual columnar augite with salitic striations, and albitized felspar, and has a tendency towards a stellate grouping of its primary constituents. Cognate xenoliths carried by this dyke are of a more basic variety of the same rock-type, but distinguished by the presence of felspar phenocrysts (21834). Another dyke (21810) with an east-north-east direction and cutting the Quartz-biotite-gabbro of Centre 3, to the north of Sìthean Mòr, is of the same class.

Certain sub-variolitic dykes may be considered here. They are generally thin and may depart from the general north-westerly direction. A 2-ft. dyke on the shore 650 yds. north-west of Faskadale (24015) has a north-easterly trend, and exhibits characters that recall the variolitic types of Ben Hiant, and also those of Ben Talaidh in Mull. Related types reminiscent of the variolitic rocks of Ben Hiant have also been encountered to the south-east (21841).

Intermediate and Sub-acid Dykes.—Intermediate and sub-acid types in Mull were most freely represented amongst the sills and composite intrusions, but formed only a small proportion of the dykes, and the same is true for Ardnamurchan. In Mull the types most frequently represented were leidleites and inninmorites.[1]

A dyke that occurs 200 yds. to the south-east of Beinn Bhuidhe, a mile northwards of Ardslignish farm and beyond the east margin of the Memoir-map (24473-4), is interesting on account of its being a typical mugearite, and the only example noted in Ardnamurchan. The dyke has a good platy jointing parallel to its margins near its edges, but a transverse structure in its interior. Microscopic sections show that this structure is determined in both cases by the parallel orientation of thin felspar plates which in cross section look like microlites, and also of minute scales of biotite. Sections transverse to the platy structure (24474, 24473A) show a fluxionally arranged mass of oligoclase felspars with rectangular cross section and length many times their thickness, granules of augite, and abundant finely distributed magnetite. In sections parallel to the platy structure (24473) all traces of fluxion is lost and the felspars appear as small, more or less equi-dimensional crystals (0·05 mm.) with an approach to rectangular outline. In these sections, also, biotite is easily visible as small hexagonal plates, which, owing to their extreme thinness, are not easily detected in sections cut across the foliation.

A very beautiful black glassy pitchstone forms a 4-ft. dyke on the shore west of Ardslignish (24472, Fig. 52 A). It carries small glomero-porphyritic groups of labradorite and moderately pleochroic hypersthene, the felspar being much twinned and but little zoned. Hypersthene and augite also occur as small idiomorphic crystals. Isolated porphyritic crystals of plagioclase have an intensely honeycombed structure that recalls the felspars of the Sgùrr of Eigg and other pitchstones from the Small Isles. The ground-mass is a partly devitrified colourless glass rendered almost opaque by a close network of skeletal growths of pyroxene, forming an interlacing rectangular pattern, and plates and minute octahedra of magnetite. A few apatites occur and the rock is minutely vesicular—the vesicles being filled with a highly birefringent chlorite. There is little doubt that this rock is related to the inninmorites of Mull and the pitchstone lavas of Ben Hiant, but a rhombic pyroxene has more or less replaced the usual enstatite-augite of these types; a rhombic pyroxene, however, was an occasional constituent of the Ben Hiant lavas (p. 139).

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[1] H. H. Thomas and E. B. Bailey, *op. cit.*, pp. 373–374.

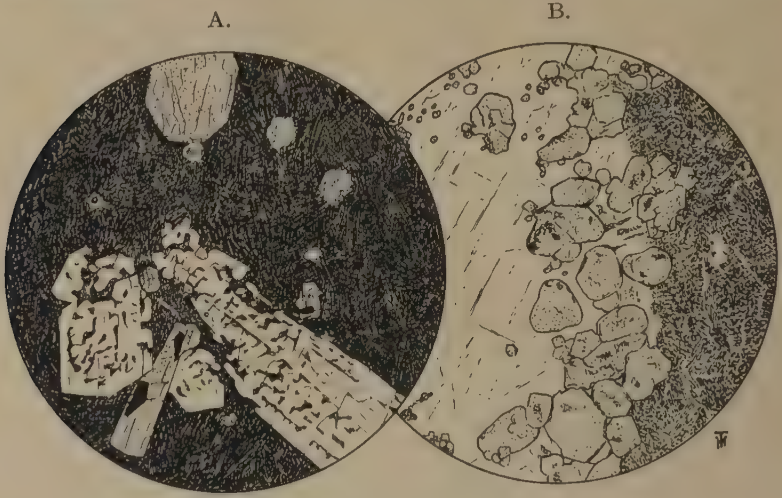

Fig. 52.—*Dyke Rocks.*

A. (24472) × 20. *Pitchstone with porphyritic felspars and pyroxene in a glassy base rendered almost opaque by skeletal growths of magnetite. The porphyritic felspars exhibit a highly characteristic spongy development and are penetrated by the ground-mass.*

B. (22425) × 63. *Amygdale from dolerite dyke showing zone of small idiomorphic garnets between turbid perthite and colourless prehnite.*

Dykes referable to the stony devitrified variety of leidleite are represented by certain non-porphyritic fine-textured rocks. The coarser of these (22429) are composed of narrow laths of oligoclase-andesine felspar, elongated small crystals of augite with here and there a cervicorn habit, and abundant plates and adherent octahedra of magnetite. Some even finer-grained rocks (22324), in which the augite is less definitely prismatic, must be referred to the same type. Hybrid rocks are, as a rule, rare in the dyke-form, but a dyke that appears hybrid in nature occurs on the shore of Sanna Bay and cuts the Great Eucrite (E). It has a granophyric base of perthitic orthoclase and quartz, but appears to contain xenocrystal material in the form of relatively large individuals of resorbed or albitized labradorite, and granules and imperfect crystals of brownish augite. There has been a development of biotite, now chloritized, and a crystallization of oligoclase as narrow individuals that carry perthitic fringes. The rock appears to be a basified granophyre.

Acid Dykes.—Acid dykes are sporadically developed over the Ardnamurchan area. They vary in composition, follow various directions, and do not lend themselves to any satisfactory grouping. Individual dykes of quartz-porphyry, for example (lettered qF on Fig. 50), are met with which run north-west, north-north-east, and east-north-east. Many of them are of late date, since they cut members of the ring-dyke complexes. Others of bostonitic or trachytic nature are probably of early date and related to the main vent-period.

Dykes of acid pitchstone and spherulitic felsite (lettered sF on Fig. 50) are fairly numerous. One of the best examples is a 5-ft. north-west dyke of glassy pitchstone (obsidian) exposed on the western shore of Kilchoan Bay, and which has been traced for more than a mile inland where it is seen to cut the Hypersthene-gabbro Ring-dyke (a) On the shore it is mainly a beautifully banded spherulitic glass, with glassy margins from which spherulites are wanting.

Of the early dykes, a fine-textured microporphyritic rock is referable to the trachytes (26675), and is similar in many respects to the trachyte that occurs as blocks in the vent-agglomerates (p. 133). It has suffered some silicification so that the original nature of its phenocrysts cannot be determined, and a good deal of microscopic quartz has developed in the ground-mass. The bulk of the rock, however, is a plexus of microlithic alkali-felspar crystals that occasionally embrace small idiomorphic pseudomorphs after augite. Another dyke cut by the Outer Cone-sheets of Centre 2, 7 ft. in width, occurs 300 yds. south-west of the Landing Jetty, Kilchoan Bay, and is a moderately coarse-textured bostonite (21839). It is composed of an interlocking network of elongated crystals of turbid alkali-felspar that, for the most part, appears to be an albite-perthite. A feature of the rock is its extraordinary richness in apatite, which, as slender needles, penetrates the felspars in all directions. It contains a moderate amount of iron-ore and a little interstitial chlorite.

Of the quartz-porphyry dykes, one cutting the Glendrian Fluxion Gabbro occurs 500 yds. north-east of Achnaha (21523). It is a pale rock in which the porphyritic individuals reach a millimetre or so in diameter. These consist mainly of quartz, but perthitic orthoclase is also represented. The matrix is a devitrified glass, now intensely turbid, but showing signs of having an originally perlitic structure. A somewhat similar acid dyke 400 yds. to the south-east of Achnaha is devoid of phenocrysts, and is best described as a devitrified felsite (21525).

One of the spherulitic pitchstones of acid composition, from the west shore of Kilchoan Bay is a 5-ft. dyke (21457). It contains perthite phenocrysts in a yellowish-brown glassy matrix that has devitrified locally with the formation of spherulites of considerable size. The spherulites are arranged in coalescing groups and strings, and are composed of alkali-felspar—both spherulites and glassy base having a refractive index lower than that of canada balsam.

Another pitchstone on the eastern shore of Camas nan Geall west of Ardslignish is remarkable in containing small phenocrysts of biotite as the only porphyritic constituent. The ground-mass is a colourless glass crowded with tufts and radiating crystallites of alkali-felspar, and rendered turbid by finely divided iron-ore.

A few dykes are difficult to place under any known heading. These are keratophyric in character, but cannot be said to constitute a type. One such dyke (21848), cutting members of the ring-dyke complex, is a fine-textured rock carrying small porphyritic individuals of albite-oligoclase. The matrix is a plexus of ill-formed laths of the same felspar with finely divided iron-ore and interstitial carbonates and chlorite. There appear to be small pseudomorphs in calcite after augite. H.H.T.

CHAPTER XXIII

DYKES OF COLL

Post-Lewisian dykes are fairly numerous in Coll. Most of them are of Tertiary date, though, as we shall presently see, a fair proportion may be Permian, and two or three may be of Lower Old Red Sandstone age. The south-east coast of Coll is about 12 miles long, and is divided into two equal portions by Loch Eatharna. Seventy dykes have been mapped on the northen half of this coast-line, and sixteen on the southern half. Exposures are rather better in the northern half, and the average thickness of dykes mapped there is only about 2½ ft. as compared with 4 ft. farther south—which suggests that several thin dykes are hidden in the south; but it is quite clear that dykes are relatively abundant in the north end of the island. In fact, it is obvious that in this direction Coll projects for some distance on to the course of the Mull Swarm of Tertiary north-west dykes.

There are some local exceptions to the general rule that dykes are more numerous the farther north we go in Coll. For instance, seven of the dykes of the southern half of the south-east coast-line are concentrated into a distance of 200 yds. at Rudha Fàsachd, east of Loch Breachacha (only two are shown on the one-inch Map).

There are two main petrographical classes represented among Coll dykes, namely, basalt and camptonite, and they are very often distinguishable in the field. There does not, however, seem to be any corresponding difference of trend. The prevalent dyke direction, irrespective of composition, is west-north-west. This is distinctly west of what is commonly noted among the north-west dykes of Mull. Individual dykes in Coll are only seen for a few yards where they cross coast sections. In this position they have often been worn away to give little 'chasms' or 'geos' between walls of the more resistant gneiss. Inland the dykes are scarcely ever visible, for they are commonly hidden under superficial deposits, even where adjoining gneiss is bare.

The great majority of Coll dykes reproduce in their field appearance the characters of the Tertiary basalt dykes so abundantly seen in Mull. Accordingly very few have been sliced. In (22149) one of them, an ophitic olivine-basalt of the Mull Plateau Type, fresh olivine is abundant in crystals that seldom reach 0·5 mm. in length; labradorite has a lath habit, shows an ill-defined microporphyritic structure, and measures in its larger individuals about 2 mm.; purple augite is ophitic; and magnetite accessory. Another of the undoubtedly Tertiary dykes proves on slicing to be of the Mull Porphyritic Central Type (22158). It contains fairly numerous tabular phenocrysts of bytownite, measuring 2 or 3 mm., and a few fresh olivines in a very augitic base; the augite is brownish and builds contiguous grains penetrated by felspar laths—

the latter showing a microporphyritic tendency; again iron-ore is accessory.

A dozen camptonite dykes have been recognized in Coll, along with two others more nearly approaching monchiquite. Almost all of them have been sliced. They are thoroughly basic rocks. In the field they closely resemble basalts, but are distinguished by a tendency to show pinkish felspathic spots, or ocelli, containing needles of hornblende or flakes of biotite. The value of such ocelli as a means of field diagnosis was first recognized in the West Highlands by the late Dr. C. T. Clough. The directions of the Coll camptonite and monchiquite dykes are as follows: one dyke runs north-north-west, four north-west, three west-north-west, three west by north, two east-west, one north-north-east. No contact between camptonite and basalt dykes has been noted in the island, though several intersections of camptonite by basalt have been recorded in other parts of the West Highlands.

The Coll camptonites aim at the Tertiary lava fields of Mull, where basalt dykes abound and camptonite is almost unrepresented. The local evidence therefore suggests a pre-Tertiary date. If this view be adopted it is natural on petrographical grounds to class them with the Permian rocks of Western Scotland as exemplified in Ayrshire. The question of age cannot, however, be decided on any evidence that has been obtained up to date. It involves many considerations which have been developed, more especially, in the writings of Sir J. S. Flett, who originally demonstrated the occurrence of true camptonite in Scotland. For a recent survey of the evidence bearing on this question the reader may turn to Chapter XXXV of the Tertiary Mull Memoir.

Petrographically the Coll camptonites contain olivine (represented by pseudomorphs), augite, hornblende, occasional biotite, plagioclase and cloudy indeterminable felspar, and magnetite in variable proportions, with apatite as an important accessory. The ocelli may include hornblende, biotite, felspar (including cloudy alkali-felspar), chlorite, serpentine, calcite, and more rarely analcite. The structure is typically panidiomorphic, and there is a strong tendency for the development of two generations of augite.

Olivine has been present in all cases, though often in quite small amount. It is always decomposed. The pseudomorphs are fairly well formed and occasionally range up to 3 mm. in length (21325, 21326, 22156).

Augite is pale-brownish in colour with a slight to strongly marked purplish shade. Hour-glass zoning is sometimes apparent (22155, 22156). Porphyritic structure is frequent, with phenocrysts of stout prismatic form measuring exceptionally 3 mm. in length (21325). The augite of the ground-mass generally occurs in almost equi-dimensional grains of stout prismatic form, often measuring about 5 mm. Narrower prisms are also found (21406, 22148). The augite is very rarely decomposed (21326).

Hornblende in the main body of the rock is always fresh and deep brown. It usually occurs as stout stumpy prisms about 0·5 mm. long, in part moulded on the augite. Sometimes it has grown almost altogether independently of the augite, and in one slice its prisms reach 2 mm. in length (21406). As a rule there is, roughly speaking, as much hornblende as augite in Coll camptonites.

Biotite is generally very subordinate and may even be absent. It is never the main ferromagnesian mineral, but occasionally (22148) it exceeds hornblende in abundance. Its colour is brown, and its pleochroism almost reaches black.

Felspar generally occurs with a lathy form, but sometimes it builds plates enclosing other constituents. It may be fairly fresh, and seems to be chiefly zoned plagioclase ranging to about labradorite in its more basic parts (21325–7, 21407). In one slice (21406) cloudy alkali-felspar in the base may be secondary. In others (21408, 22148) a turbid base occurs which may at one stage have been felspathic.

Magnetite grains are always abundant and minute apatite needles are common.

Relatively felspathic ocelli are illustrated in several of the slices. Olivine and augite are not found in these ocelli. Hornblende tends to be acicular and to show greenish tints (21408, 22151, 22156). Biotite is a little commoner than it is outside (21325, 22147–8). Felspar may build stout laths (21325, 21407, 22147, 22151) or fine feathery growths (21408, 22148). The former are in part fresh, moderately basic plagioclase. The latter are clouded or decomposed. Calcite and chlorite are common minerals, and clear analcite is well represented in one slice (22148).

The exposures of most of the sliced camptonites are indicated by the letter C on the one-inch Map. A very good example is seen on Loch Eatharna shore, 100 yds. south of Arinagour pier.

As already mentioned, two monchiquitic dykes are known in Coll, and both are represented by slices (21328, 22157). One of them comes from the north-west coast, 500 yds. west-north-west of Clabhach Church. It shows a strong concentration of ferromagnesian minerals: fresh olivine, purplish augite, and hornblende. In the very scanty base, minute prisms of felspar can be seen, while magnetite is an important accessory.

Three dykes that appeared in the field to be of exceptional type may here be mentioned. The first is a basaltic-looking dyke, 3 ft. wide, with a course just north of west. It crosses the head of Bàgh na Coille, near the north end of the island. A carbonate vein runs along the side of the dyke and penetrates it, altering it to a pale-green rock. Under the microscope a comparatively fresh specimen (26748) shows clear plagioclase laths, probably mostly more acid than labradorite, small brown flakes of biotite, and grains of iron-ore ; while other ferromagnesians, certainly including olivine, are represented by pseudomorphs, largely composed of carbonate ; amygdales show chlorite and carbonate. In a more altered specimen close to the vein (26749), carbonate and chlorite have replaced all original minerals except iron-ore. Similarly altered east and west dykes have been noted cutting the Moine Schists of Ardnamurchan (Acharacle district). On the open coast, east of the same bay, there is a small discontinuous pale dyke of non-basaltic appearance. It has not been sliced, but it closely resembles a 4-ft. west-north-west dyke that crosses the shore east-north-east of Meall nan Uan. A slice of the latter (22146) shows highly decomposed rock suggestive of certain lamprophyric types common among Lower Old Red Sandstone intrusions of the West of Scotland. Possibly all three dykes mentioned in this paragraph may belong to the Lower Old Red Sandstone suite. E.B.B., V.A.E., J.B.S.

CHAPTER XXIV

TERTIARY BASIC PLUGS AND SHEETS OF NORTH-WEST MULL

A FEW dolerite plugs and basic sheets occurring in North-west Mull are lettered respectively eD and I on one-inch Sheet 51. They have been already dealt with in the memoir concerned with the Island of Mull as a whole,[1] and the descriptions there given are repeated below. J.E.R.

DOLERITE PLUGS, 'S AÌRDE BEINN AND LOCH FRISA

A volcanic plug forms the hill of 'S Aìrde Beinn, about 3 miles east-north-east of Dervaig. Good illustrated descriptions have been given by Prof. Judd[2] and Sir Archibald Geikie.[3] From the hills south of Loch Meadhoin the plug is seen as a large knob of rock protruding with more or less vertical walls out of the surrounding almost flat lava-flows. What immediately strikes the eye from this point of view is the fact that the knob contains a central depression, the site of a picturesque lochan. There is little wonder that this hollow is often wrongly interpreted as the crater of an extinct volcano. If one approaches the hill from the north-east, the intrusive nature of the mass is well demonstrated by the fact that the edges of several flows of basalt are seen to terminate abruptly against the vertical wall of the plug.

Let us now examine this intrusive mass in detail. It is found to run north-north-west with a maximum length and breadth of 950 and 430 yds. respectively. Except for a short distance at the south-eastern corner, where the overflow-stream from the loch emerges, it has an almost vertical wall of complex nature. On examination the material that forms the outer edge of this wall is seen to consist of a fine-grained hard splintery rock, which in places shows good amygdaloidal structure. Under the microscope this outer portion proves to be the same type of basalt as that of the surrounding lava-flows, only in an altered condition due to its having been baked by the intrusion of the volcanic plug. No abrupt junction can be seen between this altered basalt and the dolerite of the plug; in fact, the one passes almost insensibly into the other. Apparently the temperature of the molten dolerite in the plug was sufficient to melt up the edge of the adjoining basalt lava, with a consequent local mingling of material from the two sources. The dolerite, followed in from its edge towards the loch, is seen to become gradually coarser in grain for a certain distance, and then to retain an almost uniform texture throughout.

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[1] G. V. Wilson and H. H. Thomas *in* 'Tertiary Mull Memoir,' 1924, pp. 156, 157, 160, 161, 292, 294.

[2] J. W. Judd, 'The Secondary Rocks of Scotland. Second Paper, On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata,' *Quart. Journ. Geol. Soc.*, vol. xxx., 1874, pp. 264–266;

[3] Sir A. Geikie, 'Ancient Volcanoes of Great Britain,' vol. ii., 1897, pp. 274–276.

The origin of the central loch now demands our attention. No rock except dolerite is exposed near its margin, and this dolerite is not different in composition from that 20 yds. or so away from the edge of the loch; nor are any fragments of ashy material exposed along the shore. The only visible reason for the presence of the loch is the occurrence of a north-north-west line of fracture, which can be traced for miles across the country, and is well seen in a cleft, on the northern face of the hill. At the south-east end the stream from the loch emerges through an opening along the same line of fracture, so that in all probability the hollow of the loch has been eroded in a belt of shattered dolerite determined by faulting.

A mile and a half north-north-west from 'S Aìrde Beinn, and on the south side of a road, a small plug forms a prominent crag known as Cnoc a' Chrocaire. It is only about 100 yds. in diameter, and is cut by a thin dyke and an irregular sheet of fine-grained dolerite.

In the other direction, a mile and a half south-south-east of 'S Aìrde Beinn, there are two more small plugs of dolerite outcropping above Loch Frisa. The more southerly is interesting as showing good almost horizontal columns. It is a medium to coarse-grained dolerite.

Petrology.—The rock forming the plug of 'S Aìrde Beinn (18064) is a remarkably fresh dolerite composed of olivine, augite, labradorite, and magnetite. The olivine is either fresh or partly converted into bright-yellow iddingsite. It is a moderately abundant constituent, builds fairly large irregular individuals, and appears to be in part of earlier and in part of later generation than the felspars. The felspar is a zoned basic labradorite that occurs in somewhat small stumpy crystals, two or three times as long as they are broad, and is ophitically enclosed by large crystals of slightly titaniferous augite. A second generation of augite of acicular habit, and in close association with minute crystals of magnetite, occurs in a chloritized residuum that fills all interspaces between the felspars not already occupied by the earlier ophitic augite.

This rock, in its felspathic nature and in the mode of occurrence of the augite, has points that connect it genetically with some of the pillow lavas of Central Mull. Specimens illustrating its metamorphic action on the basalt lavas with which it is in contact are easy to obtain (18065, 19268), and they show that the dolerite has produced more or less complete granulitization of the older rocks. In a compact basalt (18065) much granulitic augite has been formed, biotite has been produced around iron-ores, and there has been thorough recrystallization of the felspar microlites. In another specimen, an amygdaloidal basalt (19268), the granulitization is equally well marked, and lime-zeolites that occupied the vesicular cavities have, in all cases, been converted into felspar of corresponding composition.

BASIC SHEETS

A sparse development of thin tholeiitic sheets is found along the coast of North-west Mull, between Caliach Point and Ardmore Point, and extends from there inland for a couple of miles. The sheets belong, on account of their position, rather to the intrusive complex of Ardnamurchan than to that of Mull, and may be stragglers from the Cone-sheet Complex of the Ardnamurchan district. In their frequently north-west direction they repeat the tendency of cone-sheets of the earliest centre in Ardnamurchan met with along the outermost (eastern) margin of the complex, where many individuals are in part at least injected along north-west fissures (p. 176). The sheets may be described as irregular sills with a marked transgressive tendency. They dip, throughout most of the area, towards the south-west; but, at Caliach Point, they incline in the opposite direction, towards the east or north-east. Sir Archibald Geikie, in his *Ancient Volcanoes* (vol. ii., p. 158), has figured an example, from Caliach Point, cut through by a north-west dyke.

Only one specimen has been sliced. It comes from the west side of Ardmore Bay (19267), and is thoroughly fine grained, suggesting a rapidly cooled rock of tholeiitic composition. In the field the sheets are often found to weather spheroidally.

CHAPTER XXV

CLOSE OF TERTIARY IGNEOUS PERIOD TO RECENT

Subsequently to the Tertiary igneous period, erosion on a vast scale was responsible for removing many thousands of feet of rock that formed the cover for the Tertiary plutonic rocks of the Western Highlands. Widespread submergences also would appear to have taken place, for planes of marine erosion have been postulated by various writers to account for the general summit-level of 3000 ft. met with throughout much of the Scottish Highlands, and for the Lorne Plateau at about 1000 ft., typically developed in the Oban and Loch Awe district. A more recent submergence, marked by a pre-glacial coast-line, up to about 140 ft. (O.D.) is demonstrable within the present area (Sheet 51).

The Pleistocene ice-sheet effected further erosion, and to its action may be ascribed the absence of any superficial deposits of Tertiary age of later date than the lavas. Since the withdrawal of the ice there have been accumulations of alluvium, both marine and fresh water, peat, and blown sand. Repeated upheaval has affected the earlier deposits of this suite, as is witnessed by raised beaches that often fringe the coasts up to heights of about 100 ft. above the sea.

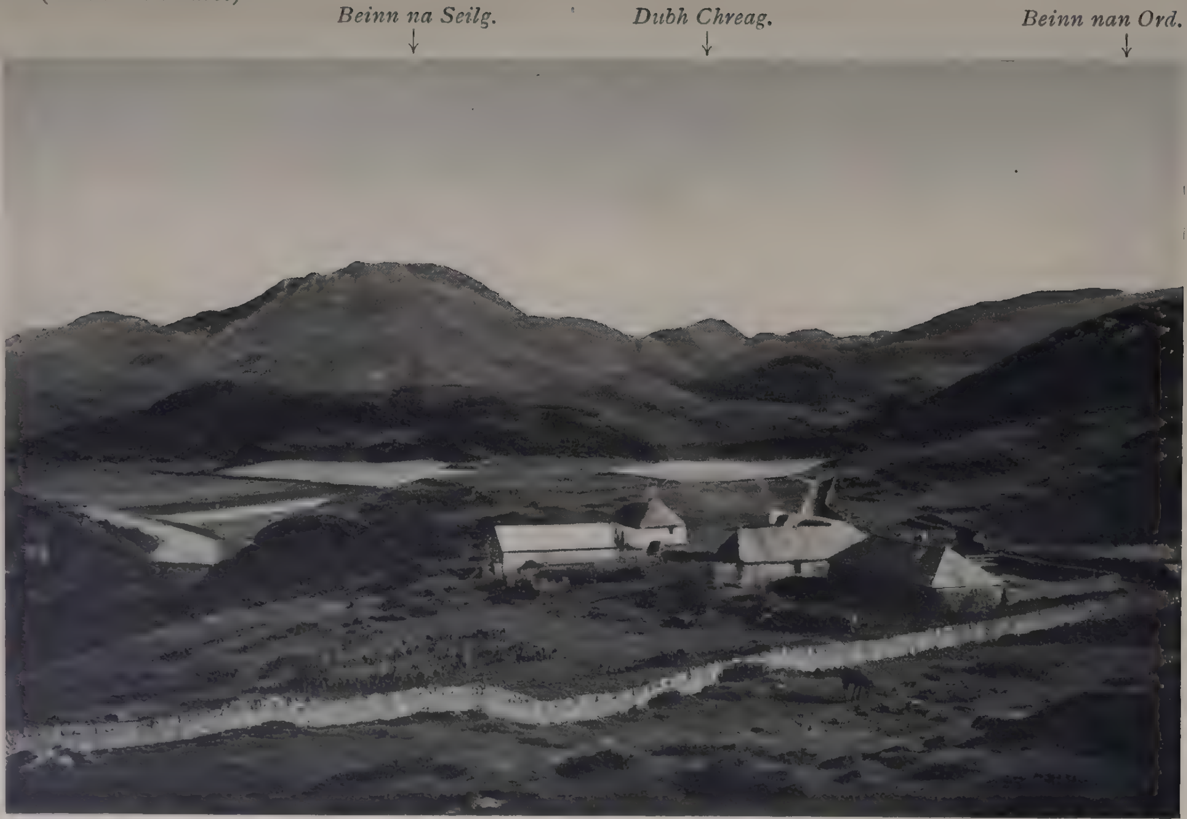
Erosion since Igneous Period

As Sir Archibald Geikie and Prof. Judd have pointed out, Ardnamurchan and the other Tertiary plutonic districts of the West of Scotland furnish particularly impressive evidence of erosion of later date than the Early Tertiary volcanic episode. Plutonic rocks require considerable cover at the time of their consolidation, and probably thousands of feet have been removed from even the highest of the gabbro summits of Ardnamurchan. Further erosion is indicated by the valley system carved in gabbro. This additional excavation has proceeded to a depth of some 1300 ft. (the highest hill of the complex, Meall nan Con, 1431 ft., in Sheet 52, consists of baked agglomerate and is therefore not considered in this estimate). The Tertiary lavas of North-west Mull have been eroded into a valley system of the same order of magnitude, for Càrn Mòr in Sheet 51 reaches 1122 ft., 2 miles inland from the sea.

Obscure Plateaux

A considerable part of the South-west Highlands can be classed as a dissected tableland, sometimes spoken of as the Lorne Plateau. The general summit-level lies 800 or 1000 ft. above the sea. It has been suggested in the Tertiary Mull Memoir that the greater part of Mull, other than the central mountains and Gribun Penin-

PLATE VII.


Beinn na Seilg.
Dubh Chreag.
Beinn nan Ord.

Tertiary Gabbro Topography, Ardnamurchan.
View looking south from Achosnich across Ring-dyke Complex of Centre 2.
(For Explanation, *see* p. viii.)

sula, may be treated as a rather vague northward extension of this Lorne Plateau. The same suggestion applies to the Ardnamurchan plutonic complex. This latter does not approach in summit-level the central mountains of Mull, where it is evident that we have to deal with relics of the dissected 3000-ft. plateau so widely recognizable in many parts of the Highlands.

Coll belongs to a set of low, ill-defined plateaux, other examples of which are furnished by Tiree and Iona, and the western part of the Ross of Mull. By far the greater part of Coll is less than 200 ft. above the sea ; and the highest hill, Ben Hogh, rising to 339 ft., stands up prominently by itself. It is probable that much of the levelling down of Coll has been the result of direct marine erosion of late Tertiary date.

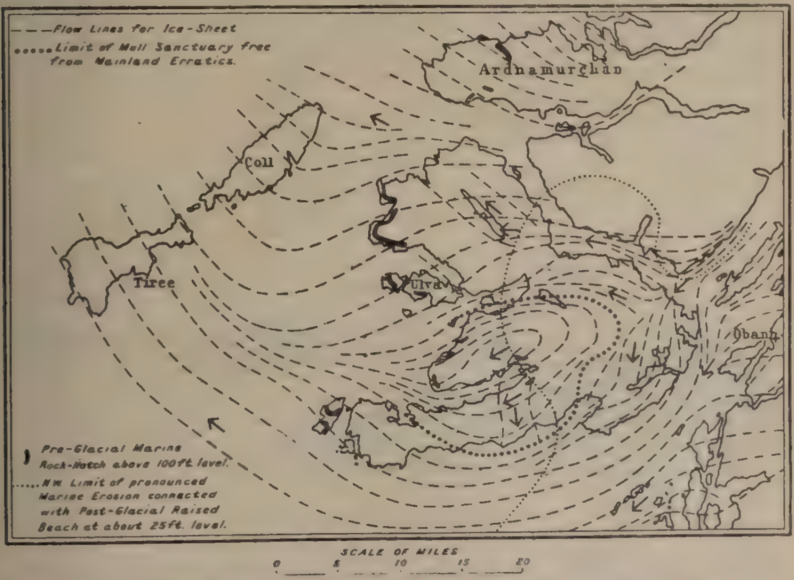

– – –Flow Lines for Ice-Sheet
•••••Limit of Mull Sanctuary free from Mainland Erratics.
Ardnamurchan
Coll
Tiree
Ulva
Oban
Pre-Glacial Marine Rock-Notch above 100ft level.
.....NW Limit of pronounced Marine Erosion connected with Post-Glacial Raised Beach at about 25ft. level.
SCALE OF MILES
0
5
10
15
20

FIG. 53.—*General Glaciation of District, and some Raised-Beach phenomena.* Quoted from 'Tertiary Mull Memoir,' 1924, Fig. 65, p. 395.

PRE-GLACIAL MARINE NOTCH ABOUT THE 100-FT. LEVEL

At a late stage in pre-Glacial times, when previous erosion had determined much of the present-day coastal form of Mull and Ardnamurchan, a submergence took place which has left pronounced traces from 100 to 160 ft. above the modern high-water mark. These traces were first noticed and investigated by Dr. W. B. Wright in Colonsay, Islay, Mull, and the Treshnish Isles.[1] As regards the part of North-west Mull that falls within Sheet 51, Dr. Wright has given the following account.

'The southern shores of Calgary Bay (Sheet 51) show only poor remnants of the pre-Glacial beach serving locally as a platform for the road. On the northern shores, however, the notch resumes the magnificent development exhibited farther south, and this it maintains round the shore of Mornish as far as Caliach Point. It is, in fact, a conspicuous object from the tourist-steamer plying between Oban, Staffa, and Iona. In one or two places its surface has an appearance of ice-moulding. An Abney-level measurement gave 115 ft. about a mile south of Caliach Point ; but similar variations (105–120 ft.) are met with here as farther south. Another estimate at the head of Calgary Bay gave 110 ft. above high-water mark, with variations between 95 ft. and 115 ft.'

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[1] W. B. Wright, 'On a Pre-Glacial Shore-line in the Western Isles of Scotland,' *Geol. Mag.*, 1911, p. 97, and with others *in* 'Tertiary Mull Memoir,' 1924, chap. xxxvi.

The pre-Glacial date of the notch just described cannot be demonstrated on local evidence. The notch, however, is obviously a product of prolonged marine erosion, for which no corresponding beach deposits have been found. In more southerly exposures, attributed to the same notch, examples have been noted of striation and ice-moulding and of cover by boulder-clay. For these the reader may refer to the Tertiary Mull Memoir.

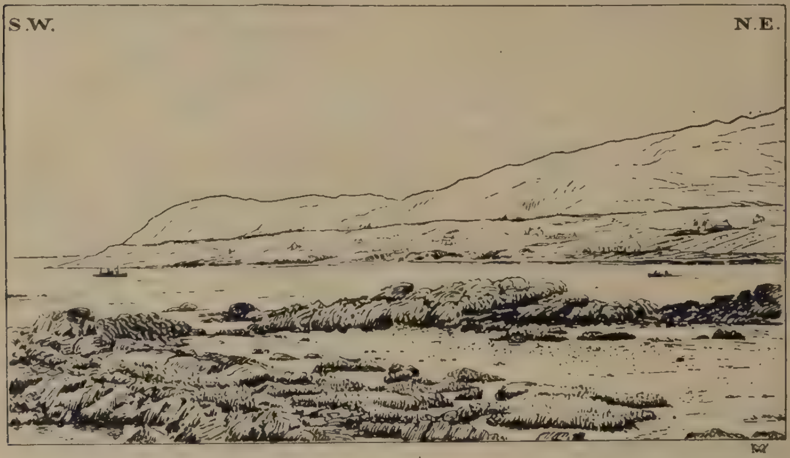

Fig. 54.—*View of Kilchoan Bay, from the east, showing Pre-Glacial Marine Rock-notch at 140 ft. along west side of bay.*

Drawn from Geological Survey Photograph No. C. 2821.

In Ardnamurchan a similar pre-Glacial marine notch is recognizable on the north-west side of Kilchoan Bay. It runs along the hill-slopes for a distance of a mile as a conspicuous feature of the landscape (Fig. 54). At its north-east end it was found to stand 145 ft. above O.D., which would correspond roughly with 140 ft. above high-water mark.

The pre-Glacial age of this high-level Kilchoan notch is strongly suggested by the following facts :—

(1) No gravels are preserved in connexion with the notch. The highest gravels are those of the late-Glacial 100-ft. beach exposed, for instance, at the Free Church Manse.

(2) The platform of the notch has suffered a modelling by erosion that does not seem to have effected the late-Glacial and post-Glacial beach gravels, which occur as well-preserved flats at lower levels.

The same notch is recognizable on the north coast of Ardnamurchan, near Achateny, and will be described in the Memoir on Sheet 52.

Glaciation

Striæ.—Western Ardnamurchan retains abundant striæ, mostly directed approximately west-north-west. Ice-moulding is extremely characteristic of the bare eucrite crags, which frequently show *roche moutonnée* forms.

In North-west Mull the striæ fall into two main categories, and are due to ice movements directed to the west and north-west respectively. Of the former we may note the following directions: north of west, a mile south of Glen Gorm Castle; west and south-west, near Dervaig; and south of west, on Ben Bhuidhe. The north-west striæ are well seen near Loch Frisa and at Dervaig.

In South-western Coll no striæ seem to have been preserved; but in the north-west half of the island the following instances have been noted, with a general north-westerly trend:—

N.W. and W. 30° N. (doubtful occurrences). North-west coast. At crossing of stream and footpath E. side of sand dunes, ½ mile west of Cornaigbeg.
N.W. North-west coast. West side of headland, ½ mile N.W. of Cornaigbeg.
N.W. Near north-west coast. Side of stream, about 300 yds. S.E. of Bousd.
W. 10° N. North coast. 80 yds. S. of Rudha Mòr, on steep rock face.
W.N.W. North coast. 200 yds. N.N.E. of Eileraig, at side of inlet.
W. 15° N. North coast. N.E. end of Sorisdale Bay.
N. 30° W. East coast. 400 yds. E.N.E. of Meall nan Uan. Head of small inlet.

James Geikie, on his map illustrating the glaciation of the Outer Hebrides,[1] has marked the occurrence of *roches moutonnées* in Coll, showing a west-north-west direction of ice-flow.

Erratics.—The Tertiary igneous rocks of Ardnamurchan were completely overridden by ice from the south-east, as is clearly testified both by striæ and erratics. Conspicuous among the latter are boulders of the Morven granite.

The same granite is found as erratics over the whole of North-west Mull. Its carry is to be associated with the westward set of striæ. Boulders of Central Mull granophyre (probably from Glen Forsa) are found near Dervaig. They were presumably distributed by the current responsible for the north-west striæ.

In Coll it is very difficult to find erratics foreign to the island, except at levels that have been reached by the sea since the withdrawal of the ice-sheet. There is, however, one very conspicuous boulder of dark olivine-gabbro which must have been carried into position by land-ice. It measures 8×7×4 ft., and stands on pale gneiss, 200 ft. above sea-level, on the rocky slopes of Ben Hogh, 300 yds. north-west of the head of Loch nan Cinneachan. This boulder (21329) is certainly derived from a Tertiary gabbro. Its most likely source is Ben Buie, Mull ; but it must be remembered that it may have been transported for some distance by floating ice previous to the advance of the ice-sheet that carried it to its present position.

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[1] J. Geikie, 'On the Glacial Phenomena of the Long Island, or Outer Hebrides,' Second Paper, *Quart. Journ. Geol. Soc.*, vol. xxxiv., 1878, Pl. xxxiii, p. 819.

Drift.—There is extremely little glacial drift anywhere in the one-inch Sheet. A doubtful deposit is shown near Clabhach, on the north-west coast of Coll. It is a rubble, mostly composed of unworn gneiss, accompanied by subordinate basalt such as might have been supplied by the dykes of the island. The matrix is somewhat sandy, with traces of water-assortment. No striæ were seen on the stones or on the pavement upon which they rest.

The material is like much of the morainic drift of the Highlands, but is not well characterized, and is possibly marine, for the exposures extend but little above the 100-ft. level. Somewhat similar rubble is seen in a few roadside pits between Arinagour and Acha. The greatest elevation here is 120 ft., and the conclusion was reached that most of the deposit was of marine origin.

Raised Beaches

In North-west Mull, a conspicuous terrace of high-level gravels, belonging to the Late-Glacial 100-ft. Beach, skirts the coast for a mile and a half southwards from Quinish Point.[1] In Ardnamurchan, within Sheet 51, the only extensive raised-beach deposits are found along Kilchoan Bay. Here, raised-beach margins are somewhat ill defined, though it is possible to identify beach-terraces at different levels. As already mentioned, high-level deposits of shingle extend up to about 85 ft. (O.D.) near the Free Church manse, half a mile inland from the head of the bay, and are classed with the 100-ft. Beach.

Raised-beach deposits at lower levels fringe the coast along the west side of Kilchoan Bay, the lowest terrace being only about 10 to 12 ft. above high-water mark. The shore-line connected with the last-mentioned deposits is ill defined, though recognizable at intervals, a contrast to the marked erosion accompanying the lowest or 25-ft. Post-Glacial Beach farther south. This contrast has been already discussed in the Tertiary Mull Memoir,[2] from which Fig. 53 is reproduced. On this figure, it will be seen that North-west Mull, as well as Ardnamurchan, lies within the northern region. In North-west Mull the level of the lowest raised beach appears to be slightly higher than in Ardnamurchan. For example,[3] at the head of Calgary Bay, the inner angle of the beach lies at a height of 20 ft. or so (h.w.m.). Again, Dùn Bàn, on Mingary Àrd, is connected by a spit of gravel rising to 39 to 40 ft. (h.w.m.), and having an angle of erosion at its base at about 25 ft. It is not clear whether this spit is a product of the post-Glacial shoreline. The amount of gravel on the modern shore is small. The beach may have an elevation of anything from 18 to 20 ft. in this district.

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[1] G. V. Wilson *in* 'Tertiary Mull Memoir,' 1924, p. 402.

[2] E. B. Bailey *in op. cit.*, p. 408.

[3] W. B. Wright *in op. cit.*, p. 411.

In Coll, raised-beach deposits are widespread. The material varies from well-washed gravel to sand and mud, and has, for the most part, been left in hollows among rocks. Along the coast, especially the north-west coast, the raised-beach gravels are to a large extent concealed by blown sand, and, farther inland, probably a good deal of the scattered peat is underlain by similar gravels. The deposits extend from sea-level up to about the 100-ft. contour. There has, however, been little tendency towards the formation of flat terraces, and it has seldom been possible to assign deposits to any particular beach-level. Accordingly a generalized raised-beach symbol is employed on the one-inch Map.

One of the most marked beach flats is at Arivirig, on the east side of Loch Eatharna. The height here extends roughly from 20 ft. up to about 50 ft., and the terrace is still partly peat-covered. Three miles farther south-west two distinct terraces have been traced for a short distance along the shores of Port na h-eitheir, but this is a very exceptional phenomenon.

At the following localities the nature of the deposits may be studied :—

(1) Near Grishipoll farm in a roadside pit : well-washed gravel of marine aspect, at about the 100-ft. level.

(2) A quarter of a mile east of Acha on the Friesland farm road : 4 ft. of dark gritty false-bedded sand with irregular wisps of water-worn pebbles, at a level somewhat less than 100 ft.

(3) North of Arinagour School : shingle on water-worn rocks, at about the 70-ft. level.

(4) At the roadside between Arnabost and Arinagour School : several pits in gravel, at about the 50-ft. level.

(5) Loch Cliad has beach ridges or spits at both ends, north-east and south-west, at about the 50-ft. level. Some of these ridges are made of boulders.

(6) Minor shingle spits are seen, at lower levels, near Rudh a'Bhinnein, on the north-west coast, and at the inlet west of Coalas an Eilein, south of Arinagour.

PEAT

In Western Ardnamurchan (Sheet 51), small spreads of peat of workable thickness are frequently met with on the lower ground between the hills. In North-west Mull, extensive deposits have been mapped south-east of Dervaig and also near the east margin of the one-inch Map at Criadhach Mhòr. Elsewhere, though peat is of general occurrence, it forms only small spreads in this lava-featured country.

In Coll, extensive deposits of peat cover the low ground (raised beach) on either side of the Arinagour–Acha road, in the south-east of the island. In the past they were largely cut for fuel by the inhabitants of Tiree, in which island peat is practically absent. In the north-east end of Coll, north-east of the Arinagour–Arnabost road, much scattered peat occurs in hollows among the rocks. The deposits are usually so small and inaccessible, however, that they are little utilized.

The occurrence of so much peat in Coll, and its almost complete absence from the neighbouring and very similar island of Tiree, is a curious phenomenon, the explanation of which is not obvious.

BLOWN SAND

In Western Ardnamurchan, a broad strip of blown sand extends along Sanna Bay for two thirds of a mile. Locally, the material is largely made up of shell fragments. In North-west Mull, a purer deposit of shell-sand (with 70 per cent. $CaCO_3$), probably blown in from the present shore, occurs at the head of Calgary Bay.[1]

A fringe of blown sand, generally rich in shell fragments, is a characteristic feature of most of the north-west coast of Coll. Local patches of the shelly debris are cemented to form a soft limestone. Towards the west of the island, blown sand comes in from the south as well as the north. Thus southern sand from Crossapol Bay unites with northern sand from Feall Bay to give the most extensive spread of the island. Dunes are very commonly developed. E.B.B., J.E.R., V.A.E., J.B.S.

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[1] G. V. Wilson *in* 'Tertiary Mull Memoir,' 1924, p. 419.

CHAPTER XXVI

ECONOMICS

In the area described in this Memoir there are few mineral deposits of economic interest, and none that is at present being utilized in any industry. A brief description of certain occurrences may, however, be of service either in suggesting possible uses or in preventing fruitless exploration.

LEAD

The only known occurrence is at Crossapol in Coll. A 'lead mine' is recorded from there in 'The (Old) Statistical Account of Scotland.'[1] The vein is described by Macculloch[2] as a narrow string of galena lying in a fissure in the gneiss, and terminating in the sea. He also states that the vein offers no chance of profit and has not been worked. It was not found possible to locate the exposure during the recent Survey.

IRON-ORE

Raasay Ironstone, Kilchoan, Ardnamurchan.—A bed of limy ironstone occurs in the Upper Lias shales of the Kilchoan district, which is correlated by means of its contained Ammonites with the well-known ironstone of the island of Raasay (p. 44). It is exposed at two localities along the shore west of Kilchoan, as indicated on Fig. 3, p. 34.

At the more easterly locality, $\frac{5}{6}$ mile S.W. of the Landing Jetty, Kilchoan Bay, the Upper Lias shales are riddled with intrusive igneous rocks, and thus occur in small disconnected outcrops. In two of these the ironstone is exposed. It is limy and oolitic, with shaly layers, and contains small Belemnites. The total thickness on view is only 2 ft., but the top of the bed is not seen.

At the second locality, west of the headland of Sròn Bheag, the strata are fairly free from igneous intrusions, but are highly baked by the neighbouring gabbro mass. The Upper Lias shales together with the ironstone are fully exposed, as described on p. 43. The bed of ironstone, 4 ft. thick, is largely altered to magnetite, but Belemnites can be recognized in it.

Analyses of the ironstone from the above two localities are given below, the first two (I and II) being of contact-altered specimens from west of Sròn Bheag, the third (III) from the west side of Kilchoan Bay. An analysis (A) from Raasay is added for comparison.

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[1] 'The (Old) Statistical Account of Scotland,' vol. x., 1794, p. 400.

[2] J. Macculloch, 'The Western Isles of Scotland,' vol. i., 1819, p. 68.

TABLE IX

Analyses of Raasay Ironstone

	I.	II.	III.	A.
SiO_2	30·15	17·07	7·73	8·58
Al_2O_3	7·89	11·08	3·53	4·24
Fe_2O_3	12·20	23·40	0·03	1·24
FeO	16·73	7·22	4·75	11·79
MgO	3·56	3·88	1·41	1·71
CaO	24·57	25·79	43·49	35·43
Na_2O	0·41	0·45	0·42	0·08
K_2O	0·28	0·28	0·26	0·02
$H_2O > 105°$	0·94	1·62	1·20	4·44
$H_2O < 105°$	0·19	0·14	0·36	1·37
TiO_2	0·33	0·42	0·16	0·28
P_2O_5	1·43	1·90	1·90	1·68
MnO	0·53	0·67	1·08	0·65
CO_2	0·99	6·35	28·57	27·54
FeS_2	0·22	0·16	4·71	0·72
Fe_7S_8	0·00	0·00	0·58	0·15
SO_3	—	—	—	0·15
$(CoNi)O$	0·06	0·05	0·00	0·04
BaO	0·00	0·00	0·00	0·00
Li_2O	0·00	0·00	0·00	0·00
C	—	—	—	0·26
	100·48	100·48	100·18	100·37

I, II, and III.—Quoted from E. G. Radley *in* 'Summary of Progress' for 1921, *Mem. Geol. Surv.*, 1922, pp. 109–110.

A. Quoted from E. G. Radley *in* 'The Mesozoic Rocks of Applecross, Raasay, and North-east Skye,' *Mem. Geol. Surv.*, 1920, p. 34.

Owing to the profusion of basic intrusive sheets there seems absolutely no prospect of the ironstone proving of economic value in Ardnamurchan. It is also of small thickness there as compared with Raasay. It is possible that the ironstone may underlie the lavas of the extreme north of Mull. If search were to be undertaken it might be well to start by boring through the red sandstone of Bloody Bay; but it will be readily understood that the prospects are not encouraging.

Iron-ore in Tertiary gabbro, Ardnamurchan.—Many of the Tertiary gabbros, that form the nose of the Ardnamurchan peninsula, contain crystals of iron-ore (magnetite) in variable amounts. The crystals are usually dispersed amongst the other minerals of which the gabbros are composed. Layers of magnetite are occasionally met with, but they are always thin and at most only about a yard in length. Such layers are found in the Hypersthene-gabbro immediately to the west of the main, southern summit of Beinn na Seilg.

The richest occurrence of magnetite as isolated crystals in gabbro was located near the inner margin of the Hypersthene-gabbro, west of Beinn nan Ord, along a north-westerly extending hollow 200 yds. west-south-west of the north-west end of Lochan Dubha, and 700 yds. south of the south end of Loch Caorach. Even in this case the magnetite only forms from 10 to 20 per cent. of the rock (p. 227). There is consequently no likelihood of the ore being exploited commercially.

QUARTZ

The Clabhach–Gorton quartz-rock of Coll (p. 13) might perhaps be employed as a source of quartz. Its steeply inclined outcrop is 200 ft. wide where it crosses the road at Acha.

COAL

A coal-seam, 2 ft. in thickness, outcrops in a stream to the north of Ardslignish farm, Ardnamurchan, 730 yds. south-east of the summit of Bheinn Bhuidhe (*see* p. 106). It is a brown coal of poor quality and no great extent, as is shown by the fact that it is not found in sections in adjoining streams. No economic value can therefore be claimed for the seam, unless perhaps for local purposes.

There is evidence that the seam is of Tertiary age. It may be compared with the lignites of South-west Mull,[1] though these are of considerably more importance.

LIMESTONE

In Ardnamurchan, limestone has been quarried and burnt for lime close to Mingary Castle near Kilchoan, and on the northern coast north of Swordle. The limestone at both localities belongs to the Broadford Beds of the Lower Lias (pp. 38–40), and at Swordle is about 80 ft. in total thickness. What appear to be the purest beds are confined to a few feet near the base of the seam, and consist of compact pale limestone. The remainder is grey limestone more or less charged with earthy impurities, and with frequent partings of shale.

Another thick seam of limestone is met with at a higher horizon on the west side of Kilchoan Bay (Inferior Oolite, p. 44). Here also the rock is impure, being grey in colour and interspersed with layers of shale. This seam outcrops again farther west, where it forms the white cliffs west of the headland of Sròn Bheag. It is there considerably altered by heat given off from the adjoining Tertiary gabbro, and to this its white colour is due. Microscopic examination (p. 236) indicates that it was an impure limestone prior to its alteration, and it is therefore not likely to prove of value for burning for lime.

MARBLE

Although beautiful marbles are known in Coll (p. 17), their development is probably too restricted to allow of exploitation.

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[1] E. M. Anderson *in* 'Tertiary Mull Memoir,' 1924, pp. 415–417.

The best outcrops are on the shore at high-water mark, 100 yds. west of Gorton farm; and at Uig, 50 yds. north-east of Breachacha Castle garden. At the former locality marble and calcareous schist extend for some 20 yds. across the strike.

SANDSTONE

Bloody Bay, Mull.—A red sandstone occurs in the sea-cliff, a quarter of a mile south-east of Ardmore farm, at the north end of Mull. It is about 50 ft. thick and can be traced for some 200 yds. The quality of the freestone is good, and it has stood the weather well where employed in the wall of a path leading to Rudha nan Gall Lighthouse (Sheet 52).[1]

Maol Bhuidhe, Ardnamurchan.—A reddish sandstone, overlying the Inferior Oolite limestone, is exposed on the shore west of Kilchoan, near the headland of Sròn Bheag (*see* Fig 3, p. 34). It is some 60 ft. in thickness, and is possibly the same bed as that of Bloody Bay. It also outcrops extensively inland around Maol Bhuidhe, where it is often comparatively free from Tertiary intrusions. These latter would, however, almost certainly add to the difficulties of quarrying.

ROAD METAL

The area is well supplied with potential road metal, which could be developed by quarrying if the road traffic justified the expense. At present most of the road metal used is taken from little pits in surface deposits or partially disintegrated rock. There is no reason to suppose that road metal will ever be exported.

PEAT

As already indicated (p. 369), peat is widely distributed. In Coll peat has been cut in the past for use in Tiree. Otherwise the use of the fuel has been strictly local.

SHELL SAND

Shell sands are met with at various points around the coasts, either along the present beach or extending inland as dunes. There is no doubt that these sands could be employed as a source of lime for the improvement of peaty soil.

In North-west Mull, at the head of Calgary Bay, there is an extensive deposit that contains over 70 per cent. of $CaCO_3$, and could be easily shipped for local purposes.

In Coll, the fringe of blown sand along the north-west coast and the stretches that extend across the western end of the island are full of shell fragments, and furnish valuable pasture for dairy cattle.

In Ardnamurchan, east of Sanna Bay, blown sands are locally made up largely of shell fragments, and might be utilized in the reclamation of peaty areas.

E.B.B., J.E.R.

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[1] Quoted from E. B. Bailey *in* 'The Pre-Tertiary Geology of Mull, Loch Aline, and Oban,' *Mem. Geol. Surv.*, 1925, p. 125.

ITY COL

APPENDIX I

ITINERARIES

ARDNAMURCHAN

THE Ardnamurchan district may be conveniently explored from Kilchoan as a centre, where there is a hotel and where a steamer normally calls from Oban three times a week. A motor road runs to Kilchoan from Fort William, and a Post Office motor bus connects up Kilchoan with the Loch Shiel–Glenfinnan boat and train daily service. From Kilchoan, roads fit for motoring, which are shown on the Memoir-map, extend to almost all parts of the district. Only the extreme nose of the Ardnamurchan peninsula is somewhat difficult to reach, but from Achosnich a track to the Lighthouse may be used for part of the way.

Suitable day-excursions from Kilchoan are outlined below. The order in which the excursions are arranged is, in a general way, the order in which the rocks met with are described in the Memoir. Page references are given to the relevant Memoir accounts. In the descriptions of routes to be taken, mileages by roads and by tracks or cross-country are indicated separately.

1. *Plateau Lavas, Volcanic Vents, and Major Intrusions of Centre* 1, *Ben Hiant.* This hill lies within the Glenborrodale deer-forest and may be out of bounds during the stalking season. Suggested route is by road to east side of Ben Hiant (6 miles) and walk back (5 miles). Inclined base of Ben Hiant Intrusion crossing an eastern spur of Ben Hiant is well seen at a distance, from the road south of Loch Mudle (p. 165).

Features of interest to be seen on walk back include: vent-wall against basalt lavas, E. face of Ben Hiant (p. 123); adjoining plateau-basalt lavas, with pipe amygdales (p. 110); pitchstone lavas, S.E. of summit (p. 127); Porphyritic Dolerite intrusive in tuff, S. of summit (p. 150); basal scarps of Ben Hiant Intrusion proper and of outlying mass on Stallachan Dubha (p. 163); pitchstone lava in stream S.E. of Stallachan Dubha (p. 128); agglomerate cliffs with recurring tuff beds, N.E. of Maclean's Nose (may be seen from above) (p. 127); traverse of South-west Vent and of Ben Hiant Intrusion along higher ground above the S.W. coast (p. 160), with columnar variolitic portion exposed in a stream W.S.W. of the summit (p. 167); basal scarp of Ben Hiant Intrusion, north side of Beinn na h-Urchrach (p. 162); across complex of cone-sheets, Augite-diorite (p. 153), and sediments, by track to Camphouse corner; and thence by road to Kilchoan.

2. *Eastern Schists, Mesozoic Strata, Basalt Lavas, Northern Vents, Cone-sheets and Major Intrusions, of Centre* 1. By road to Achateny (5½ miles). From there eastwards along the coast to beyond Ockle Point (4½ miles). Return by road from Swordle or Ockle (7½ miles).

By roadside just S. of Camphouse, Porphyritic Dolerite of Glas Bheinn (p. 142). In stream-bank E. of Camphouse, Quartz-dolerite of Camphouse (p. 152). E. of road between Camphouse and Achateny, note scarp-featuring due to massive cone-sheets of Centre 1 (p. 178).

Along shore eastwards of Achateny: agglomerate with large masses of Mesozoic strata (p. 130); contact, vent-agglomerate, and wall of Lower Lias limestone (p. 130); Lower Lias limestone, a mile N.E. of Kilmory (p. 40); Trias S.S.W. of Ockle Point (p. 36); folding of Moine Gneiss, one mile E. of Ockle Point (p. 31), and massive false-bedded pebbly Moine Gneiss farther east (p. 31).

By roadside, ⅔ mile E. of Swordle, Pabba shales (p. 42) and edge of vent (p. 130); and at Kilmory School, large Mesozoic blocks in vent.

3. *Kilchoan Schists, Mesozoic Strata, Basalt Lavas, Outer Cone-sheets of Centre* 2, *Glas Eilean Vent, and Dykes.* Shore section from Mingary Pier, south of Kilchoan, westwards around Kilchoan Bay (6½ miles).

As a guide to the section near the Pier *see* Fig. 23, p. 174; for descriptions of cone-sheets and composite sills *see* pp. 173, 184; Glas Eilean Vent, later than the cone-sheets (p. 131); Mesozoic strata west side of Kilchoan Bay to beyond Sròn Bheag (Fig. 3, p. 34, and descriptions, pp. 41–49); Pegmatite-bearing dyke (p. 351); Pre-Glacial Coast-line (Fig. 54, p. 366); Sròn Bheag composite intrusion (p. 197): note, Sròn Bheag Point is accessible only at low tide; base of basalt lavas on Tertiary mudstone in cliff W. of Sròn Bheag (pp. 104, 112); Xenolithic dyke on shore, W. of Sròn Bheag (Fig. 51, p. 348). Return from coast can be made by a steep path up the sea-cliff just S. of outcrop of Upper Lias shown on Fig. 3.

4. *Outer and Inner Cone-sheets and Ring-dykes, Centre* 2. By road from Kilchoan to Free Church (¾ mile). Thence cross-country towards the twin lochs south-east of Beinn na Seilg to west side of Beinn na Seilg; from there along Beinn nan Ord to its north-west end; across to Aodann (5½ miles). Home by road (3 miles).

Features of interest include the following: outer margin of Hypersthene-gabbro (p. 219) and Outer Cone-sheets with baked chilled edges outside it (p. 182), hillside E.N.E. of twin lochs; xenolithic strips in Hypersthene-gabbro on rocky hill north of twin lochs and E. of Beinn na Seilg (p. 222); banded Hypersthene-gabbro cut by Quartz-dolerite of Sgùrr nam Meann, both traversed by Inner Cone-sheets, W. of Beinn na Seilg (Fig. 27, p. 205); difficult intrusive junctions of Quartz-dolerite of Sgùrr nam Meann with Quartz-gabbro of Beinn na Seilg (p. 272), and of the latter with Eucrite of Beinn nan Ord (p. 273), west side of Beinn na Seilg; Quartz-gabbro of Garbh-dhail with flinty crush-rock, cut by Inner Cone-sheets, against Beinn nan Ord Eucrite, in valley at south-east end of Beinn nan Ord (p. 265); brecciation of Eucrite towards north-west end of Beinn nan Ord (Fig. 37, p. 266); traverse from this point east across old Quartz-gabbro cut by Inner Cone-sheets (p. 242), western part highly sheared (p. 243), to junction with Old Gabbro of Lochan an Aodainn (p. 244); thence north along Old Gabbro to hybridy Quartz-gabbro of Aodann on its inner side due W. of Aodann (p. 251). Home by road from Aodann.

5. *Ring-dykes of Centre* 2, *northern portion*. By road to Achosnich (4 miles). Thence along track to west coast east of Lighthouse; return *via* summits of Sgùrr nam Meann and Beinn Bhuidhe to Achosnich (3½ miles). Home by road (4 miles).

Various ring-dyke margins seen. Porphyritic margin of Quartz-gabbro (? of Aodann) against Old Gabbro crosses track S.W. of Achosnich (p. 251); junction of Grigadale Granophyre with Old Gabbro S. of track (p. 246); fine-grained margin of Older Quartz-gabbro of Beinn Bhuidhe cut by Inner Cone-sheets against Grigadale Granophyre, S. of track and E. of Grigadale Loch (p. 249); brecciated Eucrite of Beinn nan Ord, and margin of Quartz-gabbro of Loch Caorach against baked Quartz-dolerite of Sgùrr nam Meann, N. of track and N.W. of Grigadale Loch (p. 271); veining of the Quartz-dolerite by granophyre along coast S.W. of Sgùrr nam Meann (Fig. 34, p. 257), and its intricate junction with the Hypersthene-gabbro, same locality and also N.W. of Sgùrr nam Meann (p. 258); xenolithic strips in Hypersthene-gabbro, Eilean Carrach (p. 222); granophyre sheets net-veining roof of Hypersthene-gabbro, shore E. of Eilean Carrach (p. 260); summit of Sgùrr nam Meann, Quartz-dolerite veined by granophyre and traversed by a cone-sheet, all these rocks being highly contact altered (p. 257); vertical contact of Younger Quartz-gabbro of Beinn Bhuidhe with Eucrite of Beinn nan Ord, hillside N.W. of Beinn Bhuidhe (p. 276); junction of Younger Quartz-gabbro with Older Quartz-gabbro of Beinn Bhuidhe, near south summit of Beinn Bhuidhe (p. 275).

Home by road from Achosnich. On the way home, margins of Great Eucrite of Centre 3 against Quartz-gabbros of Centres 2 and 3 may be seen: margin against Quartz-gabbro (? of Aodann) at N. end of Achosnich (p. 303); and against the same intrusion above road E.N.E. of Aodann (p. 303); margin against Quartz-gabbro of Centre 3, E. of road and 2 miles from Kilchoan (p. 302).

6. *Ring-dykes of Centre* 3. Along Kilchoan–Achnaha road to Interior Complex (2½ miles). Thence cross-country *via* Sìthean Mòr to Achnaha;

by track from Achnaha to Plocaig and thence cross-country *via* northern coast to Sanna (4½ miles). Return by road (the portion from Sanna to Achnaha not shown on Memoir-map) from Sanna (5 miles).

Near (300 yds. E. of) Kilchoan–Achnaha road; sapphire locality at margin of Hypersthene-gabbro (pp. 222–233); by road, difficult junctions of Quartz-gabbro of Centre 3 against Hypersthene-gabbro (p. 285), and of Great Eucrite against the same Quartz-gabbro (p. 301). View of various ring-dykes on east side of Beinn na Seilg and on west side of Meall an Tarmachain (Fig. 39, p. 286). Circle of crags of Great Eucrite surrounding Interior Complex (p. 295, and *see* Pl. VI); thence cross-country across Quartz-dolerite Ring-dyke (p. 327 and Fig. 46); apophysis of Fluxion Biotite-gabbro of Sìthean Mòr cutting Great Eucrite (p. 331); banding in the Fluxion Biotite-gabbro (p. 330); Inner Eucrite (p. 326) and Quartz-biotite-gabbro; across Kilchoan–Achnaha road to junction of Quartz-biotite-gabbro and Fluxion Biotite-gabbro of Glendrian (p. 335); Tonalite with more acid margin (p. 337), and screen-like mass chiefly of Quartz-biotite-gabbro (p. 329); central mass of Quartz-monzonite (p. 340); thence to Achnaha and *via* track to Plocaig: junction of Inner Eucrite and Biotite-eucrite by track (p. 322); pegmatite veins in Great Eucrite E. of Allt Sanna (p. 296). N. or N.W. of Plocaig, granophyre cone-sheet (pp. 185, 197); quartz-dolerite margin of Hypersthene-gabbro against granulitized Outer Cone-sheet complex E. of Sanna Point (p. 220); junction of Great Eucrite against banded granulitized Hypersthene-gabbro, Sanna Bay (p. 303). Home by new road from Sanna.

7. *Ring-dykes of Centre 3 and Major Intrusions and Vent of Centre 1 west of Faskadale.* By road to a mile north of Camphouse (2¾ miles). Thence alongside stream to summit of Meall nan Con; from there traverse west-north-west across Great Eucrite to Interior Complex, and thence north towards northern coast west of Faskadale (6 miles). Home by road from Faskadale (6¾ miles).

In above-mentioned stream: basic portion of Beinn an Leathaid Composite Intrusion cut by thin Outer Cone-sheets (p. 157); Quartz-gabbro of Faskadale (p. 283); Fluxion Gabbro of Faskadale (p. 289); Outer Eucrite (p. 311). Highly altered screen of Meall nan Con (p. 312): contact of screen with Great Eucrite W. of Meall nan Con summit (Fig. 41, p. 299), and again on south-west side of this ridge (p. 300). Traverse across Great Eucrite to base of crags on its inner side, N.W. of Meall Meadhoin, where margin of Quartz-dolerite Ring-dyke of Interior Complex is exposed (p. 328); recross Great Eucrite ridge, noting pegmatite veins (p. 296), towards northern coast, Granulitized Outer Cone-sheet complex with Major Intrusions of Centre 1 (Quartz-gabbro and Granophyre west of Faskadale) (Fig. 16, pp. 146 and 183); agglomerate well exposed, west side of Faskadale Bay (p. 131); margin of Faskadale Quartz-gabbro against quartz-dolerite cone-sheet rock, east side of bay (p. 284). Home by road from Faskadale. J.E.R.

NORTH-WEST MULL

A convenient centre is afforded by Dervaig, while the eastern part of the district is within easy reach of Tobermory, 1½ miles east of the one-inch Map boundary (lat. 56° 37′ N.). At both places there is hotel accommodation. The one-inch Map is sufficient guide to such objects of interest as lavas (p. 107), dykes (p. 343), sheets (p. 363), the 'S Airde Beinn plug (p. 361), and the pre-Glacial beach-notch (p. 365). The base of the lavas resting on red sandstone, indicated by a note at the eastern margin of the Map, E.S.E. of Ardmore farm, is specially noteworthy.

COLL

There is a hotel at Arinagour, the port of call. During a short visit the main feature to be studied is the interbanding of sedimentary and igneous material in the Lewisian Complex of the western half of the island. It is advisable to concentrate on coast sections, and these are clearly indicated on the one-inch Map. For the sedimentary material see especially Ben Feall

(p. 21), and for the intrusive relationship of the associated igneous material see the west shore of Crossapol Bay (p. 20). Flinty crush-rock occurs at intervals along the coast north-east of Loch Eatharna (p. 26). The Coll camptonites are well represented by a dyke 100 yds. south of Arinagour pier (p. 359). The Mull Swarm of Tertiary basalts is a feature of coast sections in the north-east part of the island (p. 357). The best exposure of 100-ft. raised-beach gravel is beside the road near Grishipoll farm, 2½ miles N.W. of Arinagour (p. 369).

E.B.B.

APPENDIX II

LIST OF GEOLOGICAL SURVEY PHOTOGRAPHS. ARDNAMURCHAN

By W. MANSON

BEN HIANT VENTS.
- General Views.—2838–2840, 2844, 2859.
- Vent Junctions.—2847, 2854–2857.
- Agglomerate.—2843.
- Tuff-bed.—2848.
- Big Blocks in Vent.—2850, 2851.
- Columnar Pitchstone Lavas.—2845, 2846, 2858.
- Porphyritic Basalt Plug, junction.—2858.

BEN HIANT INTRUSION.
- General Views.—2829, 2830–2832, 2834, 2835.
- View of Junction with Vent-Agglomerates.—2860.
- Vertical Jointing.—2853.
- Columnar Basal Portion.—2833.
- Flat Columns in Variolite.—2852.

CONE-SHEETS.
- Cutting Sediments and Schists.—2820, 2824–2827.
- Cutting Ring-dykes.—2778, 2793.

RING-DYKES.
- General Views.—2781–2785, 2789–2792, 2794, 2805, 2811, 2814, 2818.
- Panoramic Views of Interior Complex.—2799–2801, 2802–2804, 2806–2809.
- Intrusive Contacts.—2779, 2793, 2812, 2813, 2815, 2817, 2819.
- Banding and Pegmatite Veins in Great Eucrite.—2786, 2787.
- Banding, Sìthean Mòr Ring-dyke.—2796.
- Quartz-gabbro.—2810.
- Net-veining.—2773–2778.
- Granulite band in Hypersthene-gabbro.—2795.

POST-TERTIARY.
- Pre-glacial Raised Beach Rock-notch.—2821, 2822.
- Roche-moutonné (Great Eucrite).—2797, 2798.
- Sand-dunes, Sanna.—2788.

Copies of the above photographs (size, half-plate) are deposited for reference in the London and Edinburgh Offices of the Geological Survey, and prints and lantern-slides are supplied at a fixed tariff.

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